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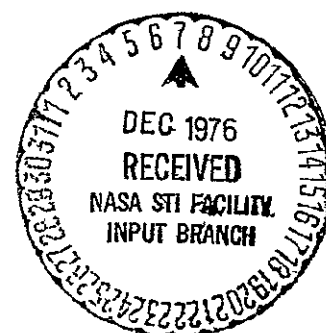


Prepared For



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Contract No. NASW-2558



OCEAN DATA SYSTEMS, INC.

6000 EXECUTIVE BLVD., ROCKVILLE, MARYLAND 20852 • 301/881-3031

Submitted to:
ECON, INC.
Princeton, New Jersey

DEVELOPMENT OF SPECIFICATIONS
FOR SURFACE AND SUBSURFACE
OCEANIC ENVIRONMENTAL DATA

Final Technical Report

Project No. 6613

June 1976

Prepared by
OCEAN DATA SYSTEMS, INC.
Monterey, California

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30 June 1976

Mr. B.P. Miller
ECON, Inc.
419 North Harrison Street
Princeton, New Jersey 08540

Dear Mr. Miller:

Ocean Data Systems, Inc. (ODSI) is pleased to submit this Final Technical Report identifying the work performed under Project No. 6613 - Development of Specifications for Surface and Subsurface Oceanic Environmental Data. This report is a composite of the four Technical Notes enumerated below:

Technical Note	Title
1	Observational Strategy for Synoptic Oceanography
2	Development of Specifications for Surface and Subsurface Oceanic Environmental Data
3	Observation and Prediction of Ocean Spectral Waves
4	Comments on Specifications for Shipboard Environmental Data Acquisition System Engineering Model

Three sets of these Technical Notes are submitted herewith. We will be happy to discuss any aspect of the report with you.

Sincerely,

OCEAN DATA SYSTEMS, INC.

Edward Morenoff, Sc. D.
Senior Vice President



OCEAN DATA SYSTEMS, INC.

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Submitted to:
ECON, INC.
Princeton, New Jersey

OBSERVATIONAL STRATEGY
FOR
SYNOPTIC OCEANOGRAPHY

Technical Note No. 1

Project No. 6613

June 1976

Prepared by
Paul M. Wolff
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1. INTRODUCTION

Synoptic meteorology, the near real-time analysis and prediction of atmospheric conditions, is commonplace throughout the world. The taking and collection of observations, both at the surface and in the upper air, is efficiently organized under the auspices of the World Meteorological Organization. Virtually every nation contributes conventional atmospheric observations through a multi-nation collection effort, while satellites, buoys, and automatic weather stations contribute even further to global atmospheric data coverage.

However, with the exception of surface parameters such as surface temperatures and sea state, the collection of synoptically useful oceanographic observations is still relatively sporadic and limited in scope. Consequently, systematic synoptic analysis and prediction of subsurface mass and motion structure is not practiced routinely anywhere to a significant extent. Synoptic oceanography, therefore, has not achieved a dynamic and progressive character.

It is clear that without a planned, orderly, and spatially logical flow of synoptically useful data, no synoptic oceanography is possible. It is further evident that without a comprehensive and well designed observational network, no such synoptic data flow is feasible. The purpose of this paper, therefore, is to demonstrate the existing need for synoptic

subsurface observations, giving special attention to the requirements of meteorology; to assess the current state of synoptic oceanographic observations; and to present a preliminary design for the Basic Observational Network (BON) needed to fulfill the minimum needs of synoptic meteorology and oceanography.

It will be seen that there is an existing critical need for such a network in the support of atmospheric modeling and operational meteorological prediction, and that through utilization of the regional water mass concept an adequate observational system can be designed which is realistic in terms of cost and effort.

The purpose of IGOSS is defined as providing more extensive and timely information on the state of the ocean and its interaction with the atmosphere. IBON (IGOSS Basic Observational Network) is a co-ordinated systematic approach to the observing system needed in order to meet the IGOSS objective, and IBON initially will be the minimum useful network in terms of spatial and temporal density and the accuracy of observation. The IGOSS System thus involves a full range of physical variables describing the state of the ocean and the air-sea energy exchange.

The immediate objective is to obtain a minimum set of surface and sub-surface temperature data on a regular basis with time and space scales necessary to define the major

features of the world oceans and to support synoptic meteorology. Special attention will be given to providing support to FGGE when the ocean data requirements of that programme are defined. IBON will later be expanded to include the measurement of other parameters as measuring techniques, instruments and resources become available.

A further important purpose of IBON is to stimulate and facilitate the research work necessary to improve the accuracy and extent of oceanographic and related environmental measurement, analysis and prediction. Such improvement should enable the consequences of environmental modification to be assessed. In particular, special experiments such as FGGE will later show whether or not IBON is an optimum observing system, and may contribute to design modifications as required.

IBON can be considered as an important contribution to the U.N. Global Environmental Monitoring System (GEMS), as it will provide information on a regular basis for assessment of the state of the ocean and its effect on weather and climate, as well as for interpretation of pollution monitoring data.

2. THE EXISTING REQUIREMENT FOR SYSTEMATIC SYNOPTIC COLLECTION OF SUBSURFACE OBSERVATIONS

Historically, and even now, a considerable segment of the oceanographic community has had little requirement for synoptic (real-time) oceanography, and therefore has no need for synoptic collection of subsurface observations. An advance in the science of predictive oceanography is possible only with establishment of a synoptic subsurface observational capability such as will be proposed below.

In the short run, the strongest demand for synoptic collection of subsurface observations will come from two groups: synoptic meteorologists, who need to improve real-time atmospheric prediction through better treatment of heat and moisture transfer at the air/ocean interface, and fisheries experts, who want to improve and better estimate catch and maximum yield.

The growing recognition of the importance of air/ocean exchange processes has stemmed from recent rapid advances in numerical weather prediction. In our opinion, this factor is the strongest existing stimulus for both systematic synoptic collection of subsurface observations and for the development of a dynamic synoptic oceanography. Consequently,

the paragraphs below will discuss in greater detail the existing synoptic meteorological requirement for a synoptic sub-surface observational capability.

2.1 Routine Synoptic Coverage

Global numerical weather prediction is now being carried out at several national centers. Most global prediction models lose skill at about 48 hours due to several deficiencies: incomplete physics, insufficient horizontal/vertical resolutions, and improper specification of initial conditions. Recent experiments by Bengtsson, Laevastu, and others indicate that improved treatment of air/ocean transfer of heat and moisture is absolutely essential if accurate atmospheric prediction is to be extended to 5-10 days. Laevastu is now conducting tests which demonstrate rapid baroclinic development in an initially zonal atmosphere with heat/moisture flux from a modeled continent-ocean-continent configuration with realistic surface temperature gradients.

Advanced, operational atmospheric prediction models do take into account the flow of heat and moisture from the ocean surface into the atmosphere. They usually utilize a recent sea surface temperature analysis (or even a climatological sea surface temperature field) as an anchor. However, they invariably keep the sea surface temperature constant during the forecast period - that is,

there is no transfer of energy from the atmosphere to the ocean.

Since the atmospheric prediction models are not truly coupled to the ocean, the effects of mechanical and thermal mixing on the ocean heat reservoir are unknown. The upper-ocean thermal structure (in the absence of any synoptic observations) can thus remain unchanged for days. An intense, but shallow, transient thermocline can appear or disappear undetected, thus making it entirely possible that the air/sea temperature difference used in heat flux computations is of the wrong sign. Since the average air/sea temperature difference over the oceans is on the order of 1-2° C, inadequate knowledge of the upper thermal structure and how it is changing is a severe limitation. One could ask, "What difference does it make if a truly coupled model is not used for environmental prediction?" Eventually, atmospheric models will have to be at least semi-coupled; that is, the gross upper-ocean changes due to atmospheric changes must be taken into account. Without synoptic subsurface observations, modelers will not know whether or not their interaction algorithms are functioning properly.

The use of climatological mean temperatures can be particularly misleading. In some ocean areas, the near-surface thermal changes over a 3-day period are of the same

magnitude as mean changes from one month to the next. If atmospheric prediction models are to incorporate hourly values of heat, moisture and momentum flux, then the subsurface observations of a minimum, synoptic oceanographic network are required to adequately define the basic ocean thermal structure which is important to this exchange.

In addition to the above requirement, there are two other broad areas of requirements for different types of subsurface observations: historical series, and special purpose investigations. These requirements are not in conflict with the network proposed herein; rather, they should be mutually complementary with it.

2.2 Historical Series

Long time series of subsurface observations at fixed locations have great utility in climate-oriented studies. Series from Ocean Station Vessels, selected fixed buoy sites, and island stations should definitely be maintained. Periodic sampling along fixed lines is also strongly supported because of its contribution toward better understanding the role of the oceans in long-term climatic changes.

The IGOSS-ITECH Committee strongly supports these efforts and urges that all such observations be forwarded on a real-time basis to support the subsurface synoptic observation network. It should be noted that the data systematically

collected by the proposed network will eventually become sets of historical series in and of itself, thus furthering climatic research.

2.3 Special Purpose Investigations and Detailed Surveys

Frequently in the process of hypothesis testing and theory building, members of various scientific disciplines carry out subsurface observations at a micro discriminatory level and/or on an extremely limited spatial or topical basis. The proposed network would in no way hinder these investigations and surveys which have frequently led to the development of new paradigms for synoptic analysis and prediction. Rather, its output could suggest new areas of intense investigation and survey.

We urge only that whenever possible, all observations capable of supporting the proposed large scale synoptic observation network be forwarded on a real-time basis.

3.0 THE CURRENT STATE OF SUBSURFACE OCEANOGRAPHIC OBSERVATIONS

Hundreds of thousands of subsurface oceanographic observations have been taken to date. Most of these have been the result of scientific expeditions designed to study the relatively localized phenomena such as eddies, upwellings, etc. Sources of these observations have included long term series from fixed points (Ocean Weather Stations) and fixed sections (e.g., CALCOFI and EASTROPAC series), and co-operative "Ships of Opportunity" since the invention of the Expendable Bathythermograph.

In this section there will be a survey of the extent of current coverage, the instruments utilized, communications procedures used, and existing data collection programs. Needed improvement areas and examples of good programs will also be pointed out.

3.1 Coverage Currently Available

The number of observations now available for subsurface synoptic analysis (any sounding less than three days old is considered to be useful in present analysis programs) is sufficient only in limited areas of the North Pacific, North Atlantic and Mediterranean. Table 3-1 shows the estimated average number of synoptic BATHY reports per month for selected ocean areas. This table is based on synoptic collection achieved through IGOSS during 1973/1974.

TABLE 3-1: Estimated Average Monthly Reports
Received in Time for Synoptic Analysis
(1973/1974)

<u>Ocean Area</u>	<u>Ave. Number</u>
North Atlantic + Mediterranean	820
South Atlantic	30
North Pacific	430
South Pacific	60
North Indian	45
South Indian	45
<hr/>	
	TOTAL 1430

The coverage is actually less adequate than shown, for the reports tend to be concentrated in smaller portions of each ocean. In these areas, the coverage is sometimes redundant; in other regions as large as one million square miles, months may pass before a series of reports is available. As will be seen, this coverage is less than 10% of the required coverage.

The coverage of LGOSS observations achieved so is shown in Figure 3-1.

3.2 Instruments

Mechanical Bathythermograph systems, (MBT), because of their known inaccuracies, should be considered only as a secondary instrument for synoptic observations. The Shipboard (SXBT) and Airborne (AXBt) versions of the expendable bathythermograph should be the basic instruments used to support

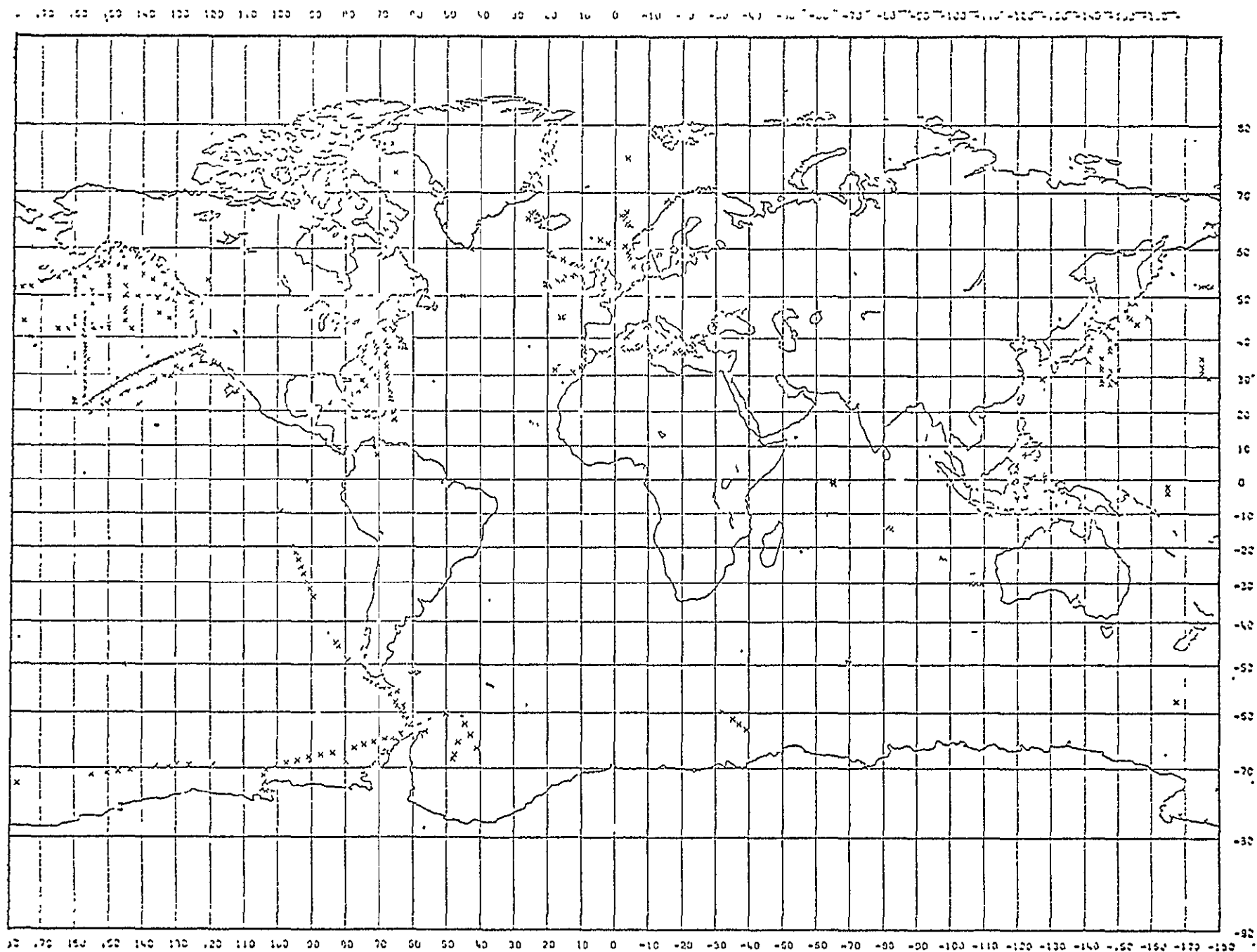


FIGURE 3-1: IGOSS BATHYTHERMOGRAPH LOCATE PLOT FOR FEBRUARY 1975.

a synoptic network for the foreseeable future. The SXBT is well-suited for use on Ships of Opportunity which cannot slow down or stop to take an observation, while the AXBT can be used to provide data from areas off the regular shipping lanes.

Chains and profilers attached to fixed and free-floating buoys are just starting to provide valuable subsurface data. In the future, the systems may become a major source of synoptic reports - particularly from the more remote areas.

The primary parameter of interest in synoptic sampling is temperature. This does not mean that observations from more sophisticated measuring systems such as STD's are not useful in synoptic programs; indeed, they should be the primary contributor at fixed ship locations and a secondary source for research sections at irregular intervals.

3.3 Communications and Codes

Code forms for subsurface observations approved by the IOC and WMO are considered to be adequate. Communications procedures for transmission of subsurface reports to shore collection stations as well as procedures for collecting such reports into bulletins for international

exchange are marginal at best. More emphasis needs to be placed on improved communications if a truly synoptic oceanographic capability is to be realized.

3.4 Data Collection Programs

The Cooperative Oceanographic Observation Program (COOP) in the U.S. is a good example of what can be accomplished in the way of synoptic sampling from Ships of Opportunity. The COOP sponsor provides SXBT launchers, recorders and probes to selected cooperative vessels. Volunteer observers typically make two soundings per day while underway for transmission to a centralized analysis center. Automatic digitizers and tape punching units are provided to those ships equipped with radioteletype facilities.

The COOP concept could be expanded significantly even to Southern Hemisphere oceans, under the leadership of IGOSS. If a group of countries were to supply the necessary equipment and expendables plus a minimal maintenance effort at key ports, many more shipping routes could be covered. Vessels of the USSR, Japan and the Scandinavian countries, which engage in worldwide commerce and fishing, would be ideal platforms for an internationally organized data collection program patterned after COOP.

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4. DESIGN OF A SYNOPTIC NETWORK

The draft proposal for an IGOSS Basic Observational Network (BON) was designed to support the following:

- a. Shipping operations
- b. Engineering operations at sea
- c. Fisheries research and operations
- d. Aqua-culture research and operations
- e. Evaluation of the consequences of man's activities in the sea
- f. Atmospheric modeling (and synoptic prediction)

In this paper, we have stressed the need for subsurface oceanographic observations in support of synoptic atmospheric prediction covering two to five days and possibly longer periods.

The design of a minimum BON should be based upon a specific goal - that is, realization of a capability which will satisfy the basic requirement while being realistic in terms of cost and simplicity. It should make maximum use of platforms already available (this is the major cost item); it should provide the horizontal resolution and geographical coverage needed to adequately define the subsurface structure, and it should provide for observations at sufficient frequency to handle the time changes of interest.

4.1 Platform Availability

Maximum use should be made of fixed platforms which already exist -- Ocean Weather Stations (OWS), buoys and offshore oil/gas production platforms. The remaining network portions can only be covered by new buoy stations, extension of Ships of Opportunity programs and, in a few cases, special monitoring by research vessels and aircraft.

It has been conservatively estimated that the world's shipping inventory consists of more than 50,000 vessels over 500 tons. These ships offer the best and cheapest means of providing the widest data coverage, simply because there are a great number at sea at all times. An internationally organized and coordinated Ship of Opportunity program must be a key element of the IGOSS observational strategy if the BON concept is to succeed.

4.2 Location of Stations (The Water Mass Concept)

Selection of the stations which are to comprise a subsurface observational network is an important and difficult task. Our goal is to arrive at a network configuration which will support realistic subsurface analysis based upon a minimum number of observations.

A regular latitude/longitude array is easiest to lay out and facilitates later numerical analysis. However, such a network (a) does not make optimum use of existing fixed stations, (b) does not necessarily fit shipping routes because of geographical constraints, and (c) does not take into account natural boundaries and homogeneities which are found in the ocean. In areas where the spatial variability of temperature at fixed depths is small or can be represented as linear functions of latitude and longitude, only a few stations are needed. This reasoning suggests that we should use the water mass concept as a basic consideration in arriving at a minimum observational network.

The shape and bathymetry of ocean basins, tidal forces, thermohaline structures, surface wind stress, and the earth's rotation combine to produce broad circulation patterns in the oceans. Even though surface wind stress can be quite variable, these oceanic circulation centers do not have random locations in the area. As a consequence,

major current systems in the world's oceans tend to be quasi-stationary and to form the bounds for somewhat homogeneous water masses. Figure 4-1 shows the approximate boundaries of the upper water masses of the ocean.

For more than half a century, geographers and oceanographers have labored to standardize water mass types and delineate the major water mass boundaries. One of the first such attempts was by Helland (1916). Wüst, in 1936 and 1939, published two very basic papers which catalogued the oceans into the 62 separate divisions shown in Figure 4-2. At about the same time, Schott (1935 and 1942) devised a somewhat different breakdown, for Schott's chart depicted the 35 natural regions of the ocean shown in Figure 4-3. In other years, Dietrich and Kalle (1957) devised the regional structure of the oceans shown in Figure 4-4. The meaning of their notations is given in Table 4-1.

While Figures 4-1 through 4-4 show some of the best known works on global depiction of water mass regions, a large amount of literature is also available concerning a typology for smaller regions and studies of one or more special features. Figure 4-5 shows a chart for the North Atlantic and Mediterranean areas (prepared by the U.S. Naval Oceanographic Office, 1967), showing areas where subsurface profiles have similar characteristics. An even more detailed

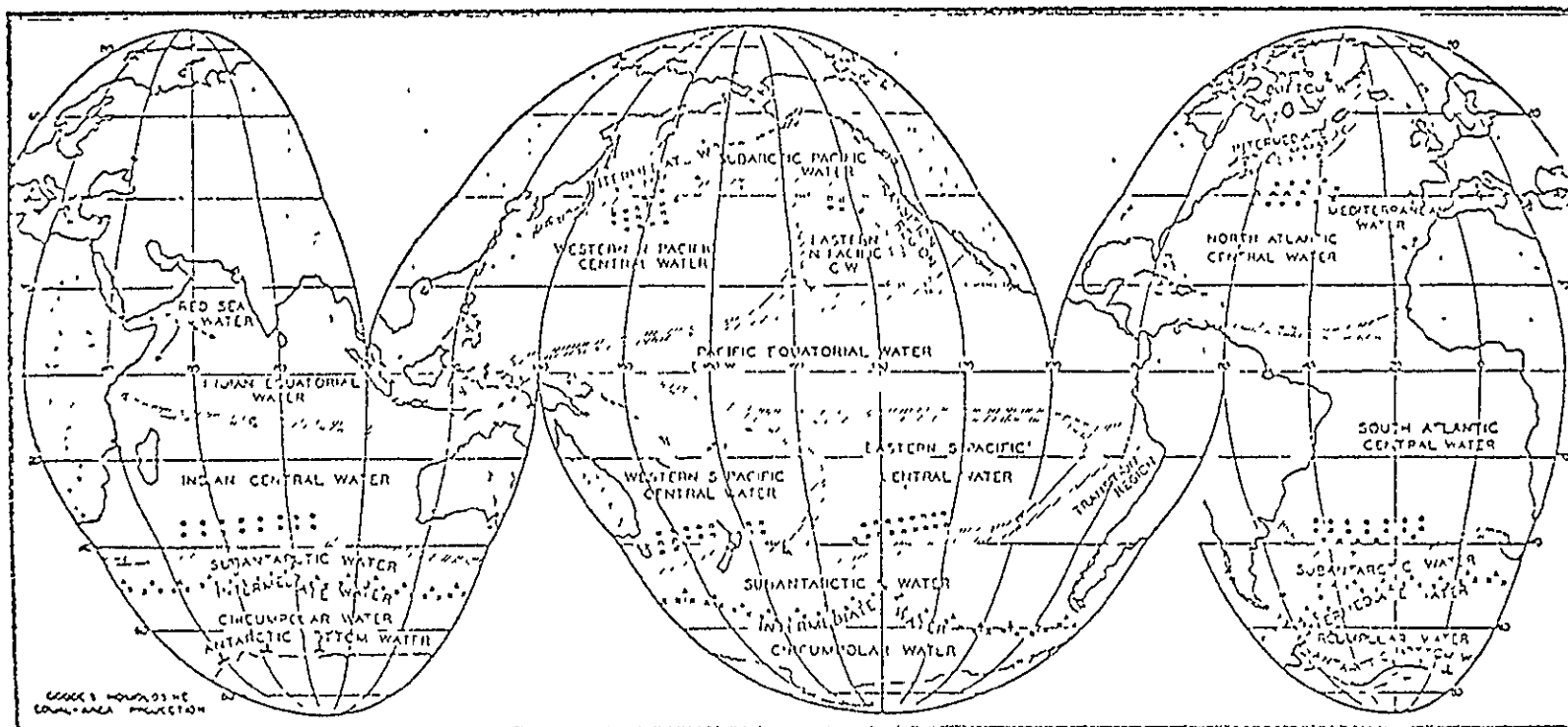


FIGURE 4-1: Approximate Boundaries of the Upper Water Masses of the Ocean
(from "The Oceans", by Sverdrup-Johnson-Fleming, 1942).

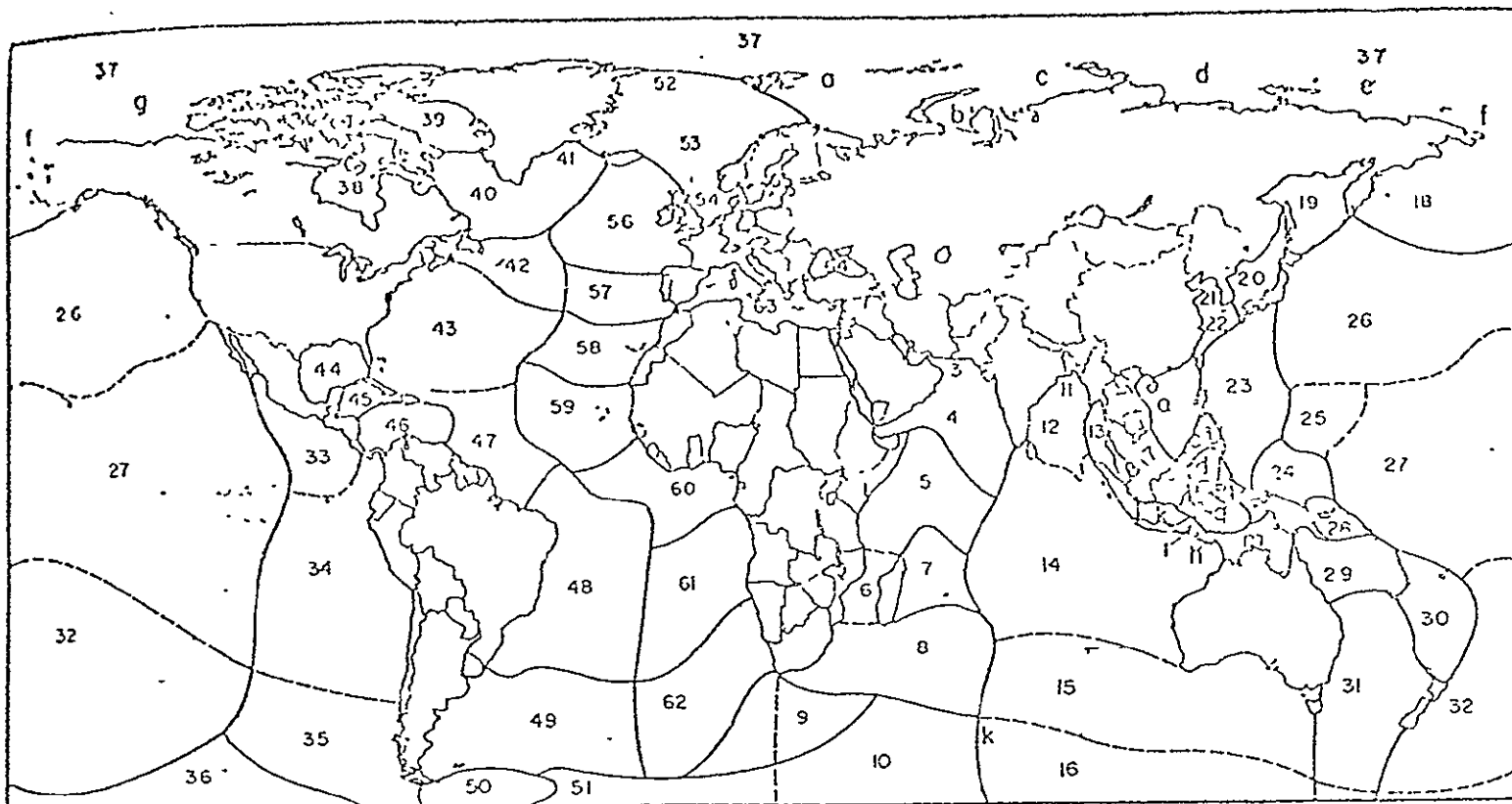


FIGURE 4-2: Division of Oceans and Seas (Wust 1936, 1939)

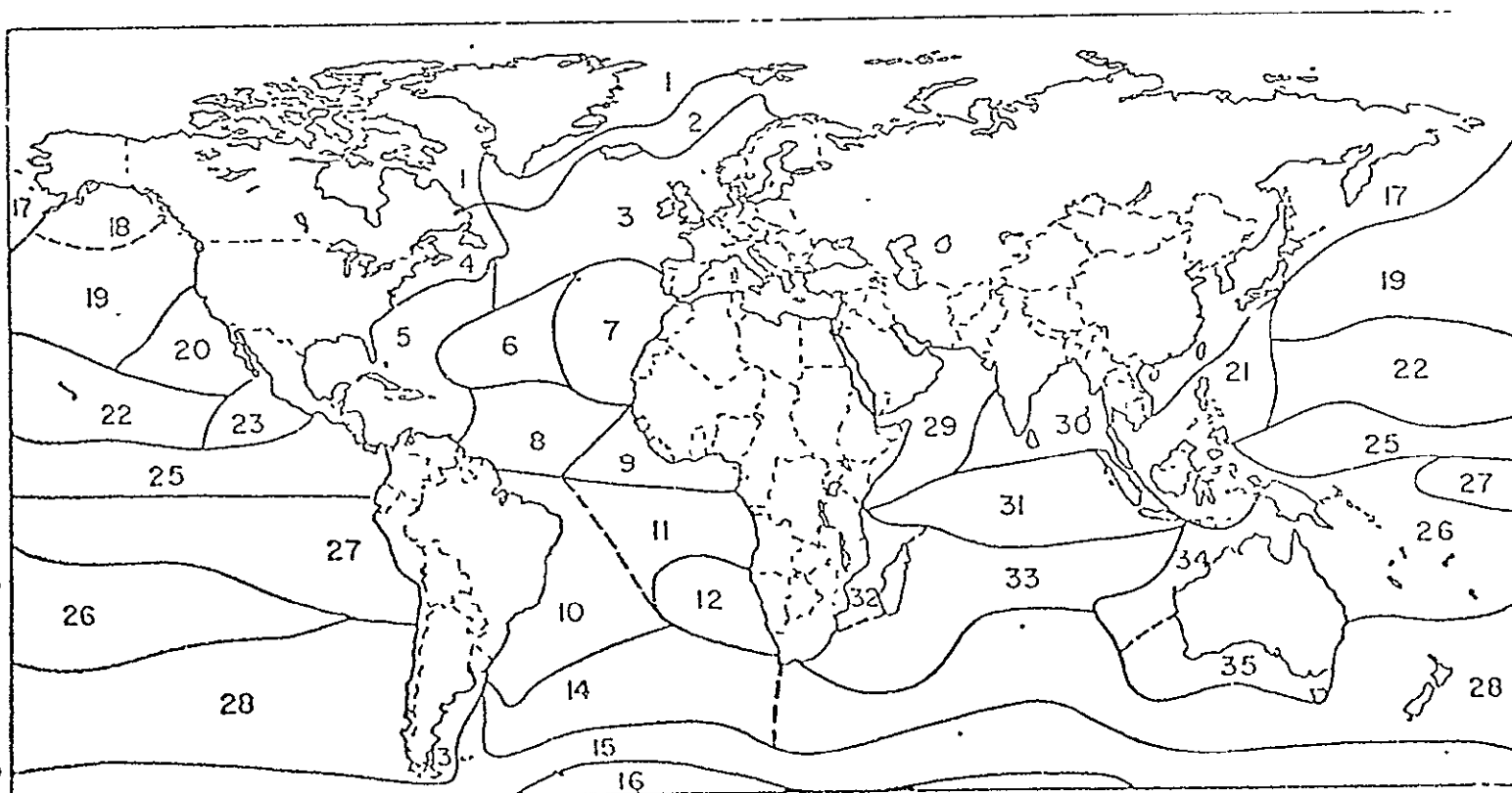


FIGURE 4-3: Natural Regions of the Oceans (after Schott)

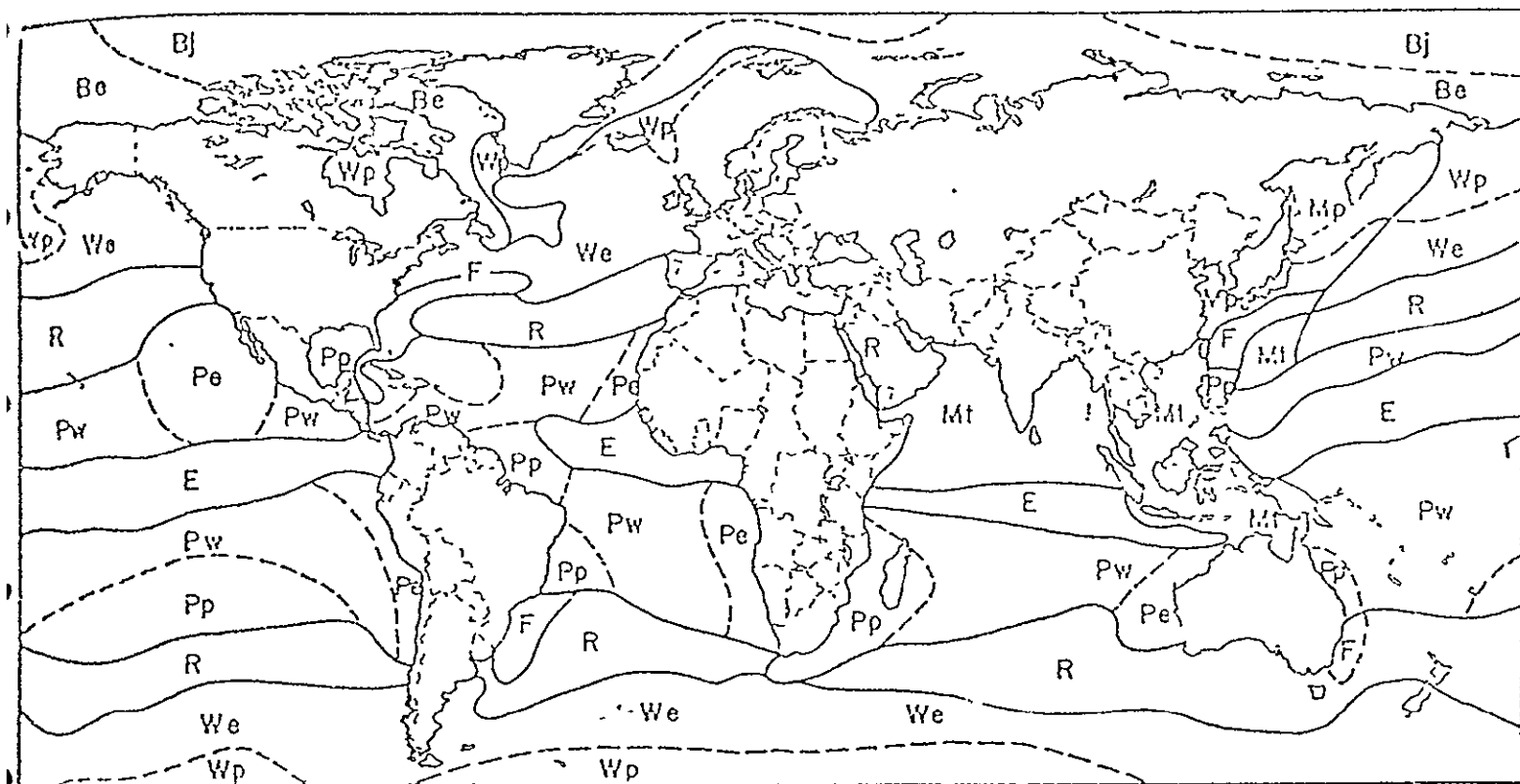


FIGURE 4-4: Regional Structure of the Oceans
(after Dietrich and Kalle)

TABLE 4-1: Notations for Regional Structure of the Oceans
(after Dietrich and Kalle)

P	<u>Trade - Current Region</u>	Throughout the year steady to very steady currents toward west.
Pe-	with strong component towards the equator.	
Pw-	clear westerly current.	
Pp-	with strong component towards the poles.	
E	<u>Equatorial Current Region</u>	At times or throughout the year easterly currents close to the equator.
M	<u>Monsoon Current Region</u>	Regular reversal of the current in spring and autumn.
Mt-	Lower latitudes (small changes in surface temperature).	
mg-	Medium and higher latitudes (great changes in surface temperature).	
R	<u>Horse - Latitude Region</u>	At times or throughout the year weak currents with varying direction.
F	<u>Free - Beam Region</u>	Throughout the year strong currents as runoff from Trade - Current Region.
W	<u>Westwind - Drift Region</u>	Throughout the year varying easterly currents.
We-	on the equator side of the oceanic polar front.	
Wp-	on the pole side of the oceanic polar front.	
B	<u>Polar Region</u>	At times and throughout the year covered with ice.
Be-	Outer polar regions; covered with pack ice during winter and spring.	
Bj-	Inner polar regions; covered with ice throughout the year.	

breakdown, with typical profiles, has been published for the Eastern North Atlantic by the French Service Hydrographique de la Marine (1967). The list of authors who have contributed to the development of water mass concepts in the ocean is voluminous; a few of the more important papers are shown in a special bibliography in the Reference Section of this report.

4.3 Distribution of the Network of Stations

(The concept of spatio-temporal variations in the water temperature).

With a view to establishing a network of ocean observation stations rationally distributed so as to provide a qualitative synoptic analysis and prognosis of the subsurface layer of the ocean (500 m), special research has been carried out on the spatio-temporal variations in the water temperature of the ocean.

A statistical analysis of these observations as to the magnitude of the standard deviations of the surface water temperature (σ) and the numerical characteristics of the temporal variations in the water column has provided a means of dividing the ocean into regions in terms of the infinite value $\sigma' (\sigma' = \frac{\sigma}{\sigma_{\max}})$ and determining the distance between observation points in the ocean in each such region. (See Table 4-2 and Figure 4-6).

A map of the distribution of the station network has been drawn up (Figure 4-7) on the basis of the data obtained.

The analysis of observation data has also shown that the diurnal variation in the surface water temperature correlates closely with the maximum diurnal variation in the temperature of the water column and is equal to $2\sigma(\sigma_s = 2\sigma)$. The relationship thus established makes it possible to determine the daily frequency of observations at each point in the network required to obtain a sufficiently accurate value of the average diurnal water temperature. The frequency of observations is fixed in accordance with the estimated nomogram (Figure 4-8).

Thus, if we know the standard deviation values (σ , σ' , σ_{\max} , and σ_s) we can divide the ocean into homogeneous regions and determine the number of stations and the frequency of observations in each of them.

This approach to the problem of the spatio-temporal discontinuity of observations in the ocean is based on physical factors, but its results are very similar to those attained by means of the "water mass" concept.

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Distance in KM	: 2000 : 1100 : 900 : 600 : 450 : 350 : 260 : 180 : 110 : 50 : 25

TABLE 4-2: Relation between σ' and distance.

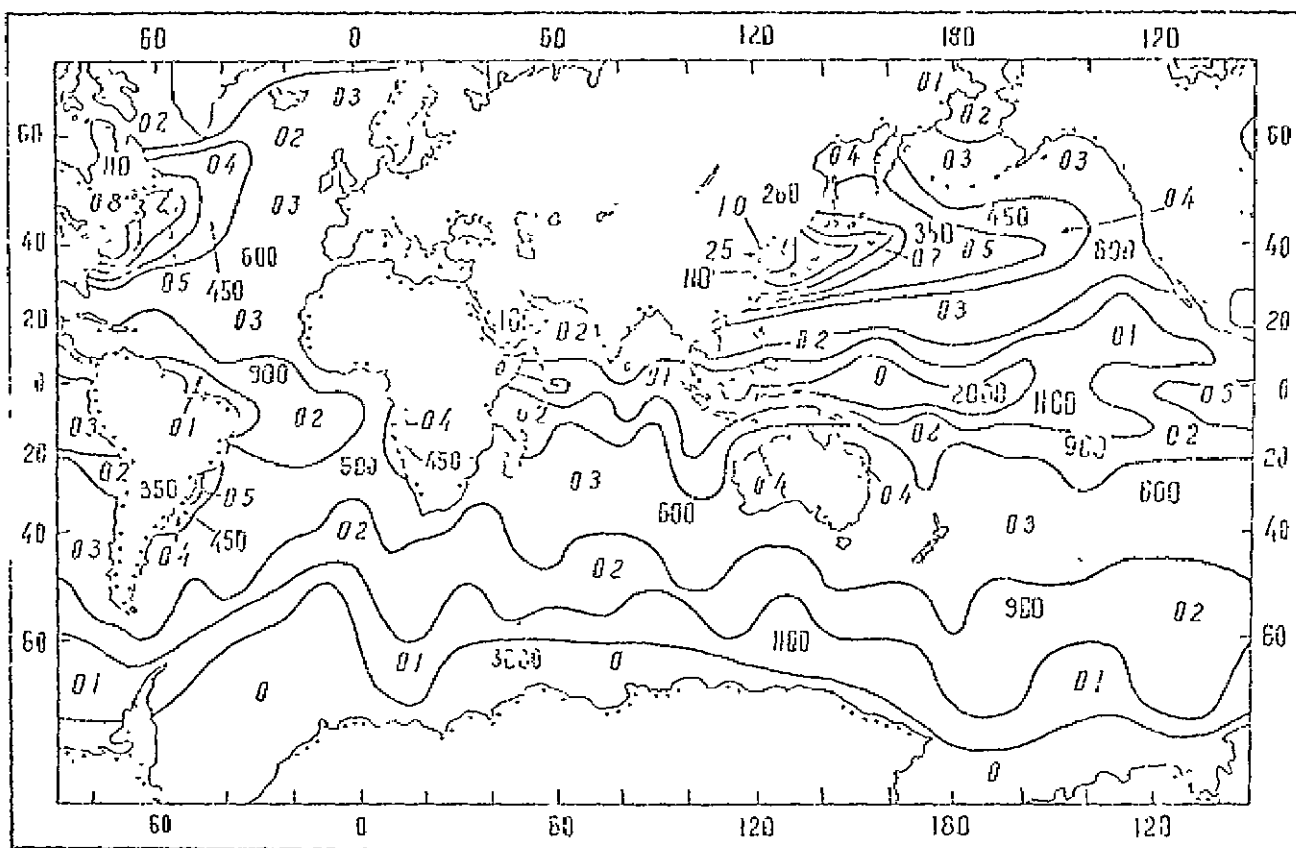


FIGURE 4-6: Distribution of values of σ' .

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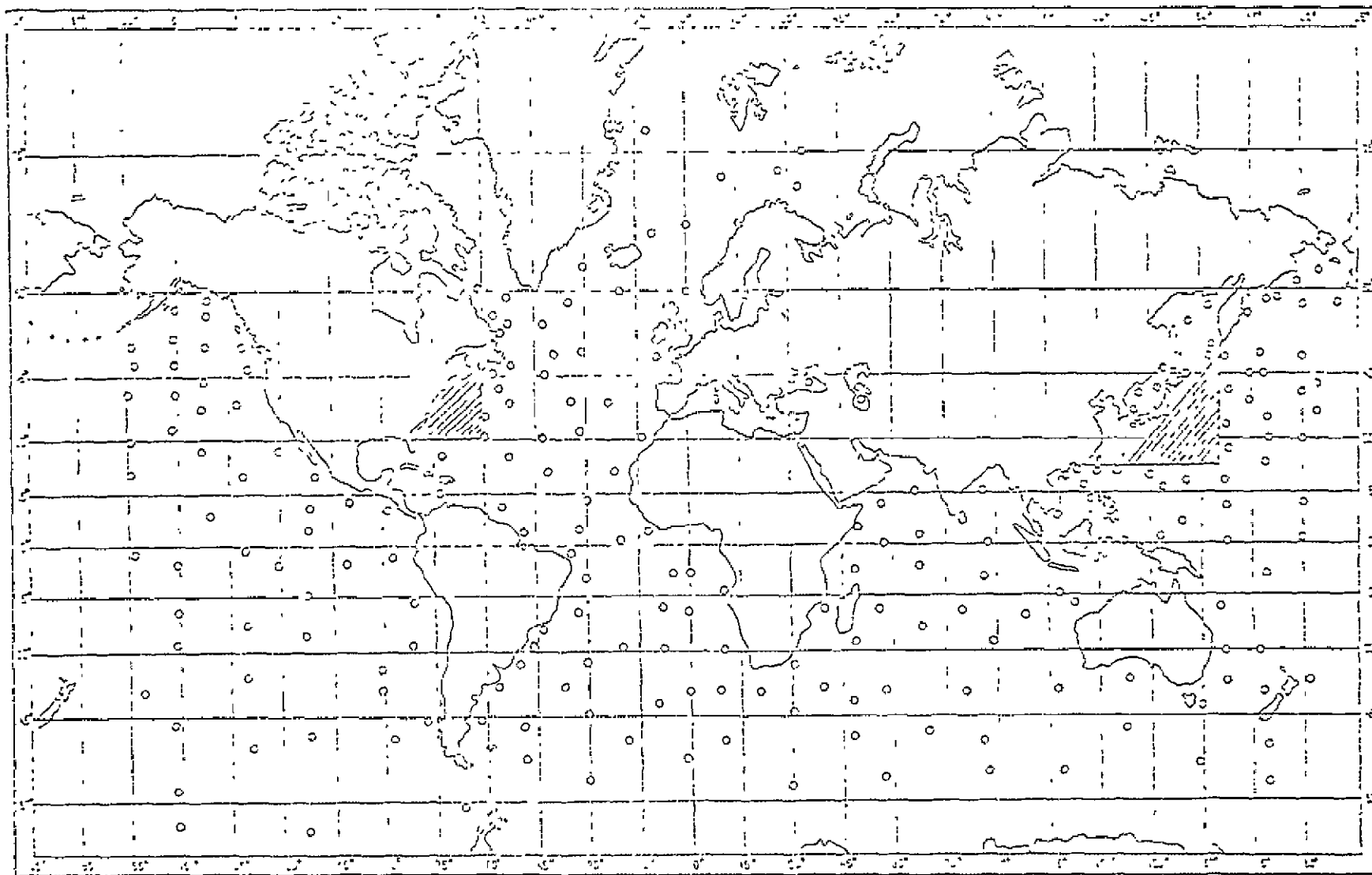


FIGURE 4-7: Observation densities related to σ' .

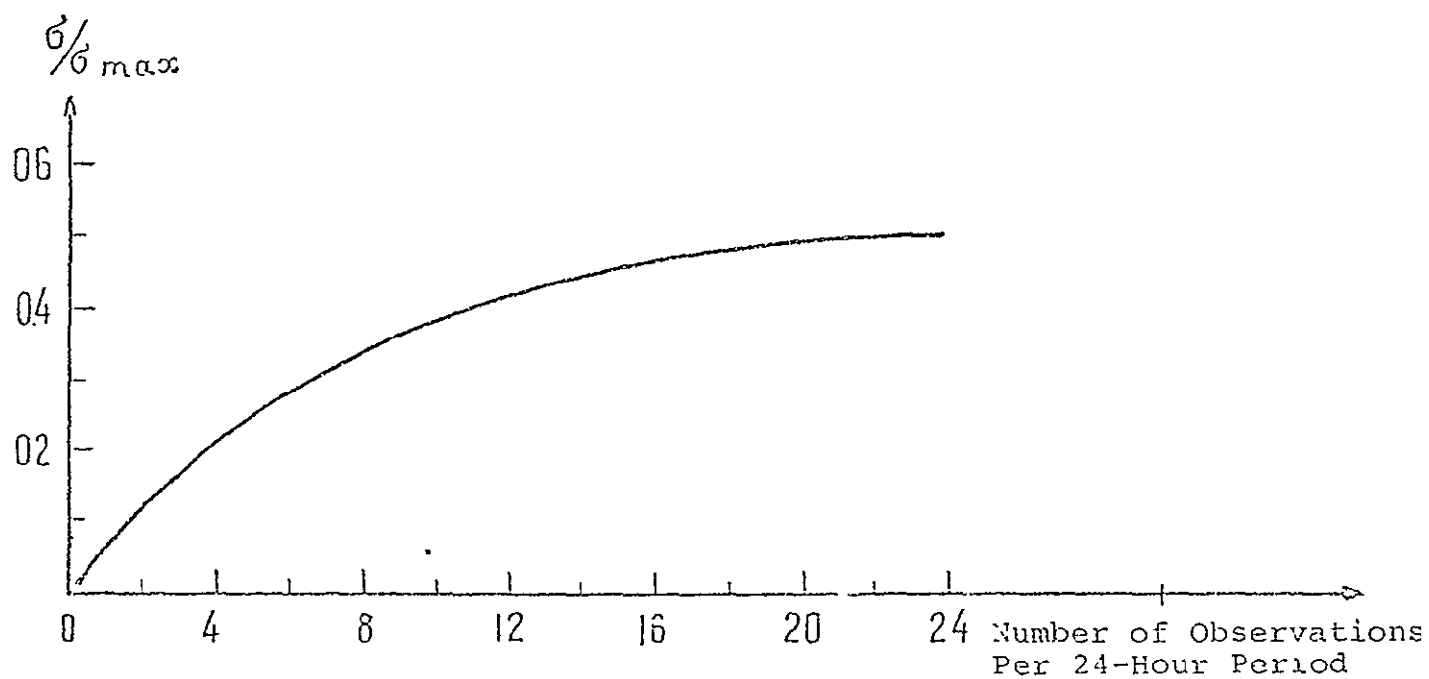


FIGURE 4-8: Chart for determining frequency of daily observations

4.4 Frequency of Reporting

If we accept the thesis that broad regions have semi-homogeneous characteristics and can be sampled by a few stations, we still need to determine how many is a few and how often should reports be required. Figure 4-9 shows the original XBT profiles (top) and parameterized profiles (bottom) taken during a special study north of Hawaii in August 1968. The upper mixed layer shows a nearly linear variation with latitude from 22N to about 40N and from about 46N to 54N with a transition zone in between. Two to three XBT observations on either side of the transition zone would define the gross thermal structures in the two major water masses.

Figure 4-10 shows the results of detailed sea surface temperature studies along the same section north of Hawaii. The top two graphs compare numerical analyses based upon ship data (FNWC) with Airborne Radiation Thermometer (ART) recordings; the graphs are about five days apart. the third graph shows the changes which occurred over this period as measured by one of the instrument systems. Notice the transition zone from about 40N to 46N with weaker gradients on either side. To adequately detect the warming which occurred during this period, one observation per day would have been required.

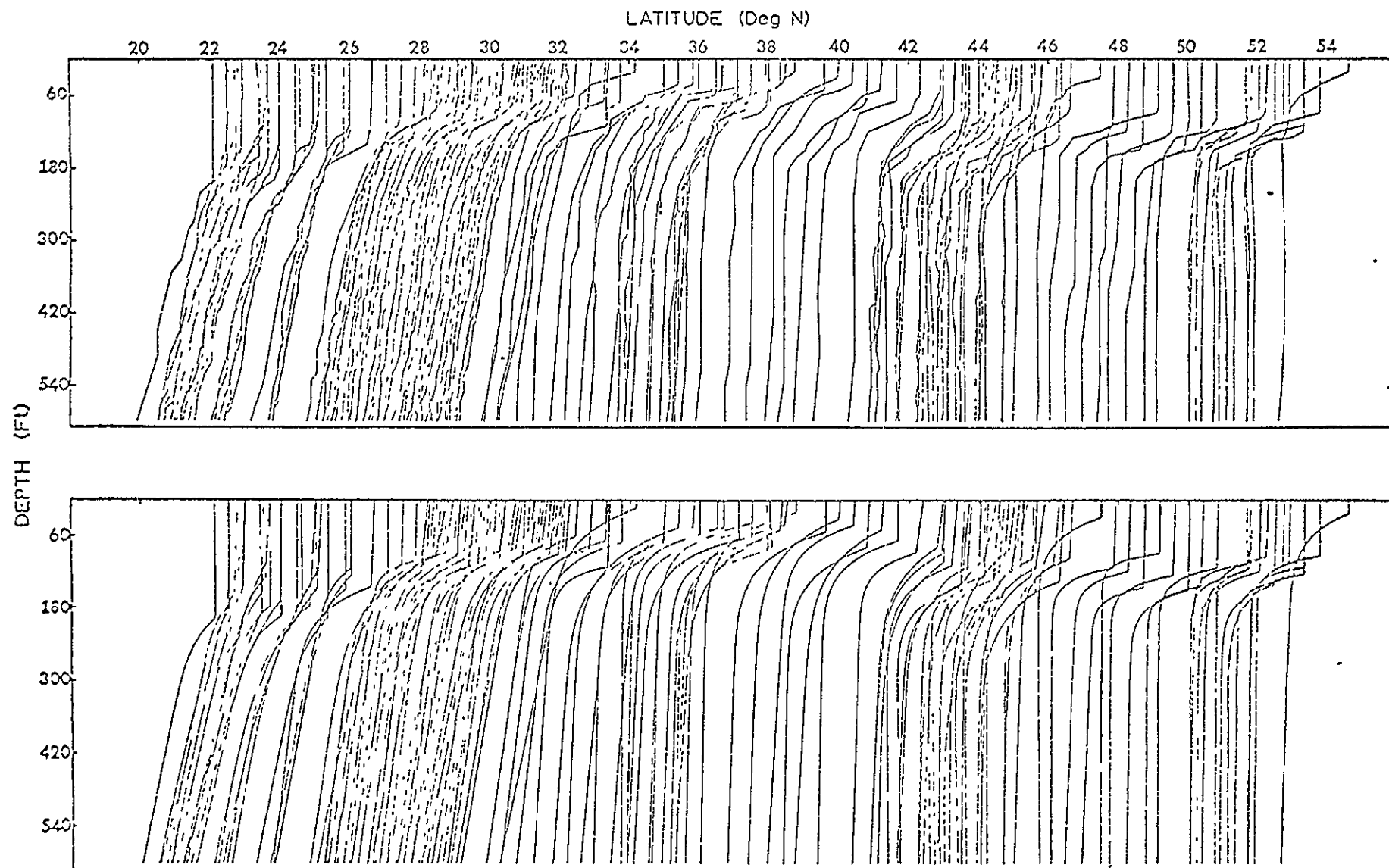


FIGURE 4-9: SXBTs and AXBTs Used to Construct a Latitudinal Section North of Hawaii in August 1968. Original Soundings (top) and Parameterized Soundings (bottom).

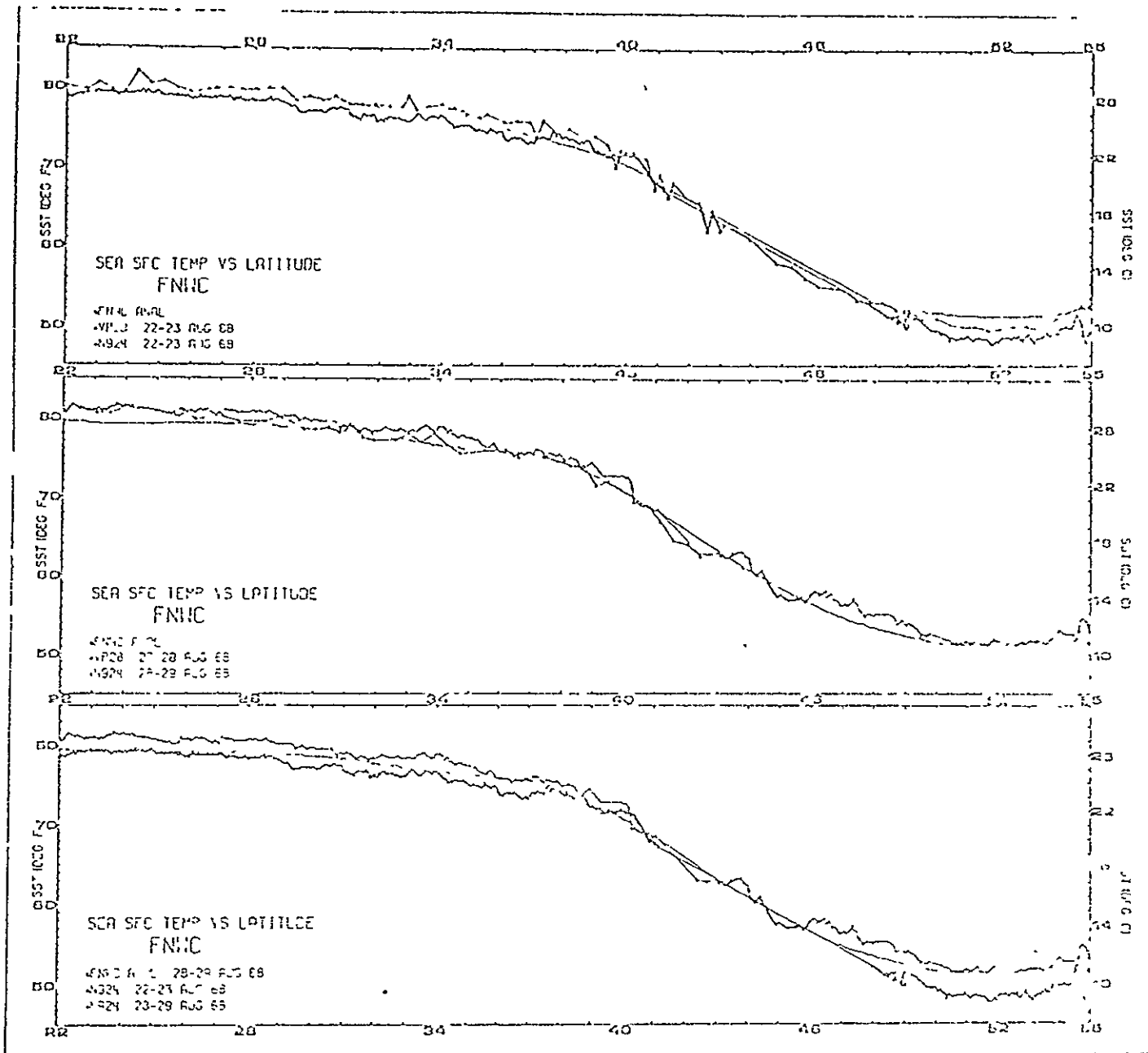
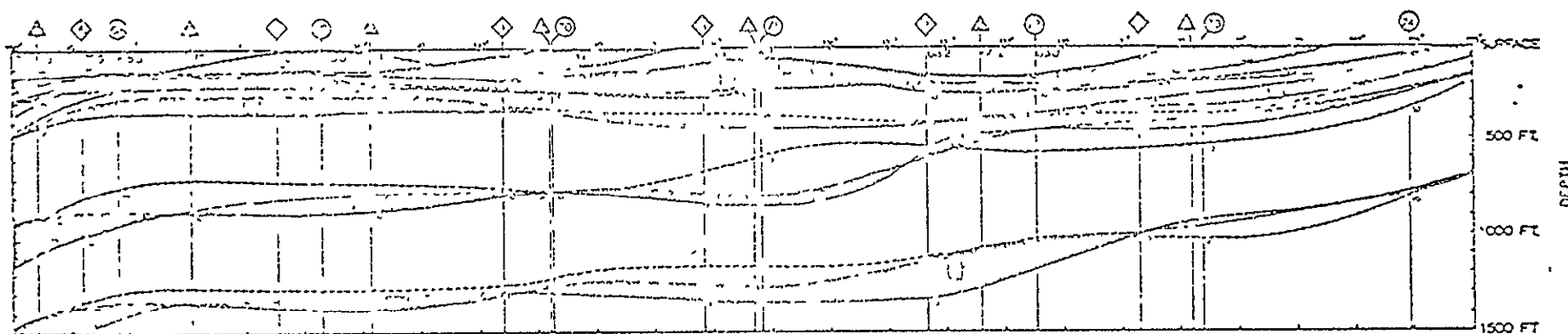
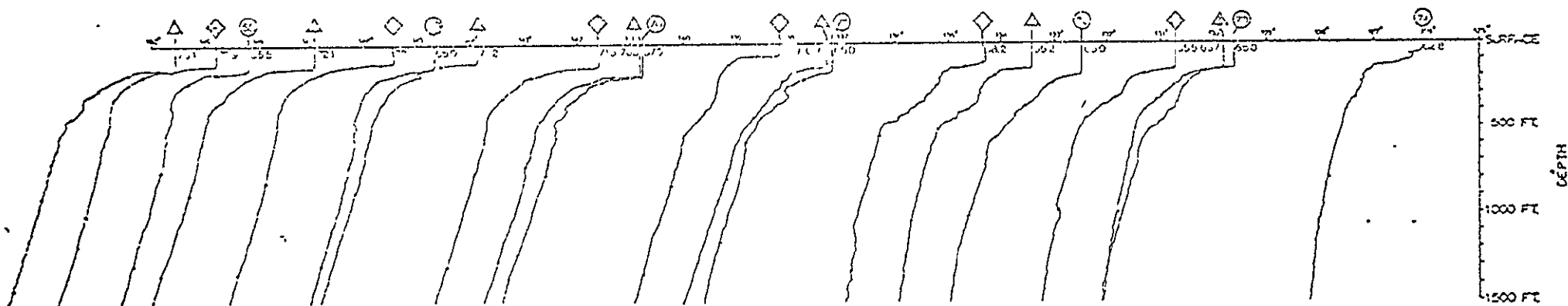




FIGURE 4-10: Numerical Analysis (FNHC) Compared with ART Recordings of SST for Latitudinal Section North of Hawaii in August 1968.

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HEATING 
COOLING 

—◇— SS LOS ANGELES Oct. 5-8, 1970
—△— SS SAN JUAN Oct. 14-17, 1970
—○— SS ELIZABETHPORT Oct. 20-Nov. 2, 1970

SEA/LAND TRANSPAC SECTION

FIGURE 4-11: SKBT Soundings and Sectional Analysis of Subsurface Isotherm Changes Revealed by Three COOP Ships. Eastern North Pacific, 1970. (from COOP Report 1970)

5. A PRELIMINARY NETWORK

In the preceding sections, we established a requirement for a Basic Observational Network (BON) to support synoptic subsurface analysis. One of the major uses of these analyses would be to specify the ocean thermal reservoir as an input to numerical atmospheric prediction. We have also outlined the logic for a network based upon the concept of daily sampling at a few points in major water mass areas. It is believed this would provide the minimum desirable coverage in the most important water masses.

Figure 5-1 shows the proposed network of stations which should serve as the IGOS goal to support subsurface analysis. This water mass chart and the stations plotted thereon represents an attempt to reconcile the most important features from all the sources discussed in Section 4 and provides several points in each area. This is a realistic configuration, and the desired coverage of at least one sounding per day near each point can be achieved in virtually all areas through the judicious selection of Ship-of-Opportunity and Research vessels. Shipping charts published by the WMO show that only a few areas in the South Pacific may have to be covered by alternative sources.

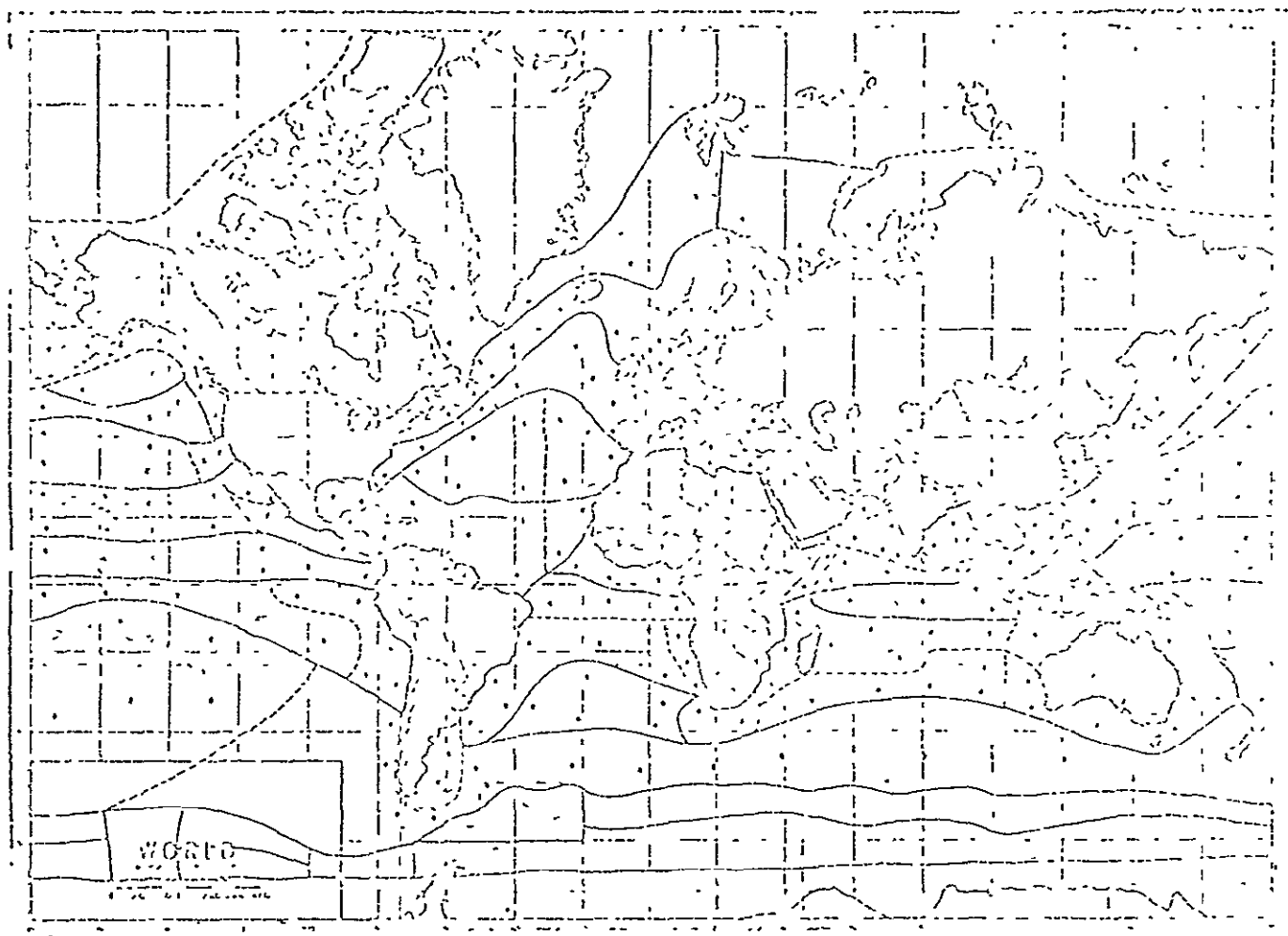


FIGURE 5-1: Chart Showing Major Water Mass Areas with
Proposed Minimum Observational Network for
Subsurface Analysis.

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Table 5-1 summarizes the above chart and gives the estimated BATHY requirements for meaningful subsurface analysis if two observations per day were requested from the vicinity of each point. The TOTALS show that approximately ten times the number now received would be required for twice-daily analysis on a global scale.

The location of the stations are not meant to be fixed and perhaps the chart shown in Figure 5-2 is a better representation of how the number of observations daily is represented by a number of reasonably located points (presumably not all in one line) which will provide the basic information needed. Some of the boundaries are relatively fixed in location. Other boundaries will show day-to-day or seasonal variability and with unusual wind conditions, some of the boundaries may disappear altogether at some times. In spite of these imperfections in the concept, the attainment of this daily coverage of soundings is considered necessary to provide the basis for analyses and predictions which can in turn be used to refine the observational strategy still further.

Also, the water-mass concept will not generally apply in the following areas:

- 1) within 100 miles of land,
- 2) where the water is less than 100 fathoms deep, and
- 3) in areas of major current boundaries.

TABLE 5-1

ESTIMATED BATHY REQUIREMENTS FOR MEANINGFUL SUBSURFACE ANALYSIS

AREA	APPROXIMATE NO. OF WATER MASSES	APPROXIMATE NO. OF OB- SERVING POINTS	DAILY OBSERVA- TIONS REQUIRED	PERIOD MONTHLY OBSERVATIONS REQUIRED (Best distribution)	ESTIMATED AVE. NO. of BATHYS REC'D PER Month 1973/74
NORTH ATLANTIC OCEAN	14	56	112	3360	^a 820
SOUTH ATLANTIC OCEAN	10	30	60	1800	30
MEDITERRANEAN SEA	2	8	16	480	^a 5
NORTH PACIFIC OCEAN	18	70	140	4200	430
SOUTH PACIFIC OCEAN	12	36	72	2160	60
NORTH INDIAN OCEAN	7	21	42	1260	45
SOUTH INDIAN OCEAN	8	24	48	1440	45
T O T A L	71	215	490	14700	1430

^a Combined North Atlantic and Mediterranean

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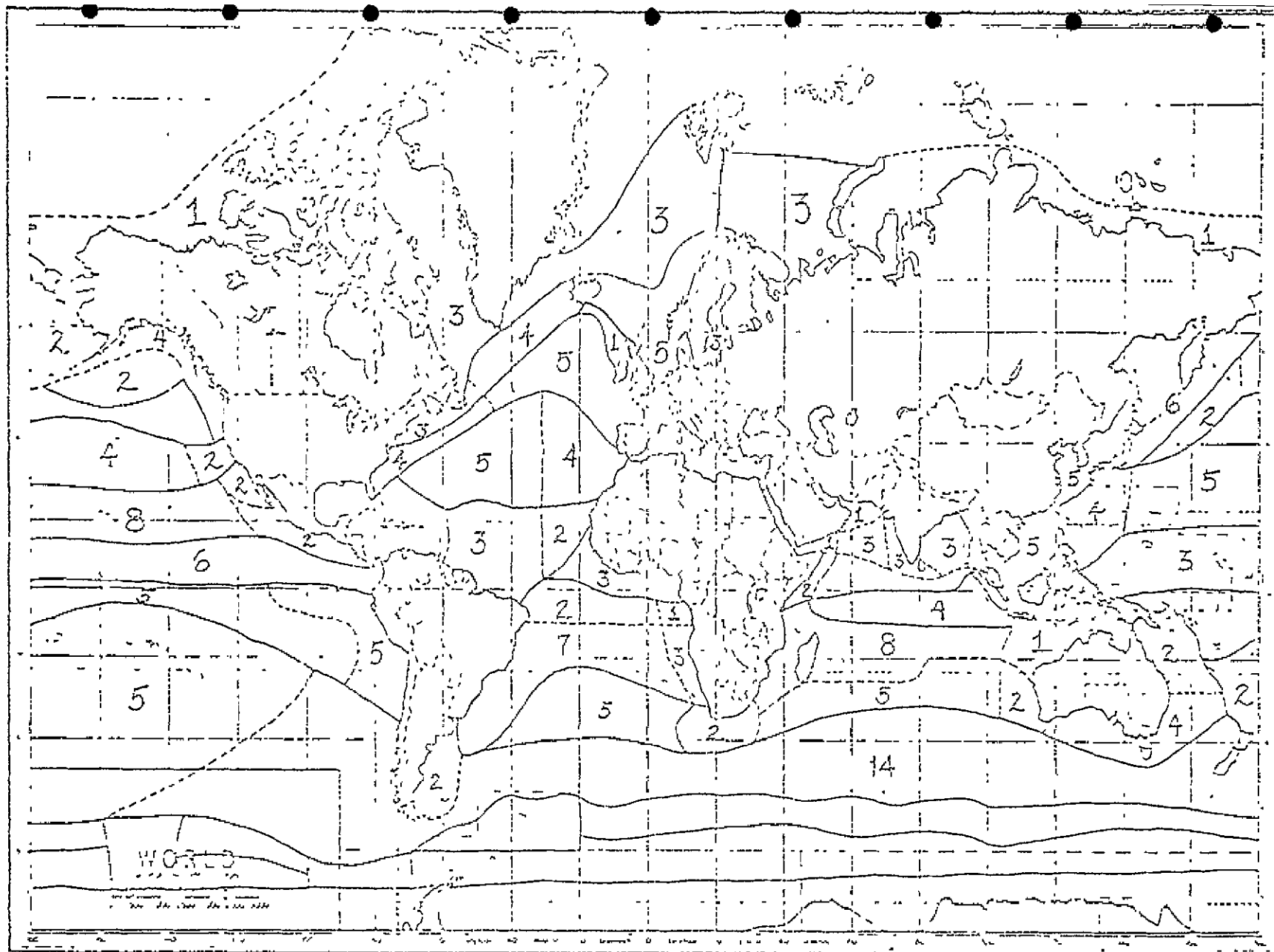


FIGURE 5-2: Chart showing major water mass areas with the number of observation stations needed to provide basic coverage.

6. PRIORITY OF AREAS FOR ATTENTION

Since the IGOSS program is achieved through the voluntary efforts of the member states of the WMO and IOC, the areas in which these member states are willing to expend effort to obtain a basic coverage will probably be the first to achieve a satisfactory observation density. Nevertheless, certain abstract principles should apply in determining priorities. High priority areas should include those in which the present observational density is low, areas which have been shown to have important qualities for atmospheric telecommunications (Flohn, 1965; Johnson, 1975; Bjerknes, 1969), and also areas of particularly high influence (Hansen, 1970).

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DEVELOPMENT OF SPECIFICATIONS
FOR SURFACE AND SUBSURFACE
OCEANIC ENVIRONMENTAL DATA

Technical Note No. 2

Project No. 6613

June 1976

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DEVELOPMENT OF SPECIFICATIONS
FOR
SURFACE AND SUBSURFACE OCEANIC ENVIRONMENTAL DATA

An effective Oceanic Environmental Data Collecting System, of necessity, involves very complex and interrelated elements. Since many critical decisions are necessary before it is possible to implement such a system, there is a major need to assist the essential decision making process at the highest level so that the interaction of the functional and financial elements of the complete system may be grasped in a dynamic and intelligible manner.

In view of the obvious complexities faced, it is suggested that perhaps a multi-phasic effort may be appropriate, such as the following:

1. Generate supporting information and devise methods of presenting the information so that essential system decisions may be made.
2. On the basis of decisions made in phase 1., design the system in detail. Implement proper hardware and performance specifications for procurement. Generate appropriate tests and calibration specifications. Specify acceptance criteria.
3. Develop system implementation schedules and related hardware procurement schedules. Formulate and define elements of supporting structure and ongoing logistics and hardware documentation needs.

Historically, oceanographic instrumentation and sensor development have proceeded in an almost haphazard fashion, frequently as follow-ons to specialized instruments developed for small-scale oceanographic research programs. Most instruments are now built for a price and a specific market potential. In general, government procurement practices, along with other consumers, have tended to ignore instrument reliability. They have almost universally been unwilling to pay the initial cost for high reliability and have tended to choose cheaper, less reliable instruments and to depend upon a rather massive system of maintenance and repair, involving technicians and engineers at every point. It is now quite apparent that this method of procurement has not been very successful. Government figures show that it is immensely expensive and that it may cost anywhere from 10% to over 100% of an instrument's initial cost simply to keep it operational for one-year. It is further evident that one of the consequences of such policy, as presently practiced, leads to

an almost unmanageable annual budget, simply for maintenance and repair. There is, thus, a unique opportunity to re-evaluate the way in which we have been proceeding in instrument and hardware procurement and to examine carefully, in detail, the interrelations between the requirements of various models and analyses and the data acquisition costs in relation to acceptable data resolution errors, along with data telemetry, upon the models and analyses.

As a further historical reference, oceanic data collection systems have evolved essentially as people-intensive systems at every level. It is not presently possible to devise systems that can operate without people, but it appears appropriate to examine projected data collecting and processing systems to determine where it is essential to use people and to give special attention to the machine/people interfaces.

Another factor should be considered, since most of the data which will be collected will, in one way or another, be ultimately archived in data banks. Entirely aside from the impact of bad data upon modeling, it appears necessary to consider the consequences of the "pollution" of data banks by the bad data.

As an imperative task, it would appear appropriate to examine the entire concept of "people problems". This will have to do with all aspects involving people from perhaps recruitment, through training, to even considerations of costs chargeable to a real system, due to allocation of funds which is necessary for retirement (pensions, etc.) of the people involved. There are also problems relating to logistics, which may be further broken down into transportation, the necessity of maintaining spares, the people and space costs relating to maintenance inventories, and instrument repair and technical training facilities. All of these parameters do figure in actual systems' costs. It may be advisable to develop a current, rather popular concept, at least being utilized by the Air Force and the Pentagon, under the general term "buy to cost". This is meant to be the total system cost over a period of "X" years and not necessarily the initial costs.

There will be a significant interaction between the sensitivity of the models and the accuracy, as well as the resolution band, of the required data. As a subsection to this aspect, it would be advisable to give attention as to the weighting of all data with respect to accuracy, reliability, etc. It is assumed that the model does not react with the same sensitivity to all measured parameters. Therefore, such weighting should be developed. Consideration should also be given with respect to the basic system design, whether it is to provide for future increases in either accuracy or sensitivity or both for the data collection. An appropriate design will effectively tend to resist obsolescence and

provide for upgrading at minimum cost in the future, should this prove desirable.

System readout time (time required to collect data from the entire system) is an important design and cost parameter. Decisions will have to be made early on with respect to this function. (Part of Phase 1 consideration)

Since an overall systems review and systems design is exceedingly complicated, it may well be appropriate to consider a computer program for support of the system design and perhaps develop software for the use of computer interactive graphics so that it will be practical to visualize the interaction of the various parameters and costs, as they are varied. This should also make possible the clear understanding of the benefits and penalties due to the variation of selected parameters in the system design.

It would appear that this is an opportunity to make what might well be considered essentially a fresh start in the whole process and mechanism of collecting data from large-scale systems. This being the case, it appears to be highly desirable to approach the entire problem from the standpoint of systems engineering. This will involve the development of innumerable subsystems and the relationship and interactions between them. It is assumed that it will be possible to develop a suitable algorithm for these relationships. Since this will probably be one of the first opportunities to look at a system of this type reasonably objectively, it will be difficult to arrive at a unanimous agreement as to the nature of various interactions and, as a consequence, will complicate the development of the appropriate algorithm.

The entire relationship of instrument reliability and cost will need to be developed extensively and provisions made for optimization. System reliability must be determined for every point and perhaps related to the number of data points collected in the entire system and the consequences of the loss of a portion of the data. Data loss, undoubtedly, is highly significant when there are few measuring stations, but the loss of a station becomes less significant as the number of stations increases and some means of quantizing these relationships is desirable. It would also be assumed that a given station would be sensing numerous parameters and here, of course, as mentioned earlier, it will be necessary to develop a means of establishing the ranking or priority of any given parameter in relation to the overall system functions. Here, the question is precisely the dependence of the model on the various parameters and the different ways in which the model reliability will degenerate when different types of input are in error or missing.

Another consideration which should be given is precisely to what extent automation of the system is feasible or appropriate and this, in turn, depends upon the entire system requirements. A significant point here, as developed

in the IBOND paper, is that it becomes very easy to handle problems relating to changes of data format, etc.

There have been serious problems encountered in the past with respect to procurement of hardware, etc. by government agencies. It would be well to profit by mistakes of the past and to take steps that will facilitate obtaining the desired quality of product. To begin with, this means that clear-cut specifications must be developed, free, insofar as possible, of misinterpretations and ambiguities. Aside from being precise about instrument and performance specifications, in view of the fact that no recognized national or international standards presently exist for the calibration of most marine instruments, it is considered that, at a very minimum, the procurement documentation should define how the instruments are to be tested and what is considered to be acceptable and unacceptable performance.

From the standpoint of instrument specifications, there is a serious problem with respect to how tests are to be carried out, etc. with respect to proving the design from the standpoint of reliability. The difficulty here is that, since reliability is often specified in thousands of hours, there is no realistic way to carry out tests in real time and, as a result, specialized methods have been developed to give statistical significance to more abbreviated testing. There are a variety of methods that have various degrees of acceptance which are considered appropriate for the demonstration of valid performance in lieu of the real time testing. These should be carefully selected and spelled out as to how these are to be applied. It should also be explained that, since this may be considered a somewhat controversial area, suggestions and comments from the prospective suppliers, especially on this point, would be welcome.

In view of some of the problems stated in earlier paragraphs with respect to technical specifications, etc., it would seem appropriate to include in the documents, especially in the procurement documents, albeit this is somewhat unusual, a glossary of terms as used. This would be an effort to avoid misunderstandings and to be certain that the terms mean the same thing to all parties concerned.

It does not appear that any large-scale system employing data telemetry, presently being contemplated, may be considered which depends 100% for transmission via satellite or HF radio. The complicating factor is that the costs of stabilized dish antennas for use on shipboard have been running substantially higher than originally anticipated. Costs are presently ranging between \$30,000 and \$50,000, exclusive of radio equipment. This means that retrofitting older ships with satellite communication capability will be exceedingly slow and, for that matter, may never be universal. However, the relatively high cost of the antenna system is not

so prohibitive for new ship construction. The conclusion here might well be that HF frequencies will be required for many years to come and that it is essential to accept this as a fact. If HF is, indeed, to be retained for data transmission, it is exceedingly important to shift all marine data traffic from commercial HF circuits, used for ship-to-shore service, to the specialized HF frequencies set aside for oceanographic data communications. It should be further emphasized that, if HF is to be employed, this will mean a parallel program must be undertaken for upgrading or installation of a few HF receiving systems at carefully selected, optimum sites. Costs, etc. should be developed for various means which would need to be undertaken to accomplish this shore automation. This is essential if automation of the system is to be pursued and to eliminate the inordinate delays on commercial circuits and the problems with ships radio operators.

It is considered beyond the scope of the present document to go much into detail with respect to the future of data telecommunications. It is perhaps appropriate to point out that there are other alternatives to the MARISAT and the other, rather expensive, stabilized dish antennas. For example, the U.S. Navy, with the assistance of Motorola, has developed the SSR-1 shipboard satellite communications system which does not use a stabilized dish antenna but rather four fixed antennas utilizing pre-detection electronics. The present costs to the Navy for a ship installation, complete with coax cables, antennas and associated electronics, is presently \$20,000. Motorola estimates the cost for commercial production on a basis of 200 units at no more than \$11,000, including electronics. Further down in the cost spectrum, is the present, rather simple electronics and antenna systems being employed on some of the NDBO data buoys communicating with the GOES satellite, which are very modestly priced and are operating at approximately 100 bits per second.

One point, however, which does appear clear at present is that it will probably be cheaper, for shipboard, buoy, and shore-based installations, to utilize completely independent and preferably automatic systems, working at modest data bit rates, rather than trying to piggyback with very expensive systems.

It may well be that this is the very first opportunity that has occurred to design and engineer a complete data and processing system from the systems engineering standpoint. In the past, it has, to a large degree, been necessary to accept and incorporate oceanographic and meteorological instruments which are generally available and accept the constraints which they impose. As mentioned, this is probably the first opportunity to let the model and analyses requirements drive the instrument and sensor specifications and not the reverse. At the present time, no manufacturer specifies the MTBF (Mean Time Between Failure) on marine or meteorological instruments. Rather, the major emphasis is on "easy repairability" or

"maintainability". This is a rather tacit admission that there are reliability problems and deftly sidesteps the whole instrument reliability question. Such a policy inevitably locks the customer into heavy operating and maintenance costs with substantial capital investments in spares with the supporting technicians and logistics.

An exceedingly important aspect of systems costs relates to the maximum accuracy and resolution of the required sensor instrumentation. This, in reality, should be dictated by the requirements of the models and analyses which will utilize the data. It must be emphasized that excess accuracy and resolution beyond that which is considered essential for modeling purposes is exceedingly expensive and cannot be justified. It should also be pointed out that data accuracy and resolution beyond those which are essential also adversely impact upon the costs relating to instrument reliability, as well as overall system performance. Though it may appear obvious, it is perhaps appropriate to point out that the lower the risks of a system malfunction, the higher the reliability. For all practical purposes, these may be considered reciprocal relationships. For example, an instrument which possesses low reliability will, in fact, have a high risk of failure or malfunction. It also appears that there is no practical way of designing a system or instrument presenting a zero risk, since this would also mean that the instrument would be infinitely reliable. The real challenge is to devise a system capable of performing at an acceptable level of risk and at an acceptable cost.

It may be highly desirable to consider the pros and cons with respect to tradeoffs between high accuracy data and a few data points versus more numerous data points and lower data accuracy in relation to model needs and consumer requirements.

There is a need to examine objectively the kinds of data products required, as well as how to present or display data products. Attention also needs to be given with respect to possible archiving requirements. Decisions should be made with respect to "quick look" requirements and at what point in the system this is desirable or essential. The "quick look" capability, if required, should be carefully engineered and designed for the optimum presentation of data for people interpretation. It is essential to examine the system as a whole, not from the present, conventional viewpoint but what may be desirable for a completely revised and new system.

As a convenience in interpreting and observing data, it is clear that the system's data flow could be monitored by microcomputers and be designed to sound alarms or signals. It would be necessary to provide adequate memories for the microcomputers so that they could present the critical data to an appropriate display system. Such microcomputer systems could sound alerts to any pre-selected environmental situation

which may be based upon real time values or rates of change of the parameters and even specific parameter interaction. Dedicated microprocessors may have great merit in this application. These could be keyed also to geographic locations, which may be of special interest or require essential monitoring, such as large cities or industrial or marine facilities. Such a system, made possible by microcomputers or microprocessors, for monitoring specific parameters would appear to be essential since the huge mass of data which individuals are called upon to interpret tends to guarantee that there will be a possibly unacceptable, built-in time delay before a potentially dangerous situation may be recognized. To a large degree, such a provision removes the burden of a constant alert from individuals. Further, it should be clear that dedicated microcomputer or microprocessor monitoring systems would become increasingly valuable as time goes on and a better understanding of the involved processes is generated.

A major problem of any large-scale system is the system/people interface. It is quite obvious that any large-scale data collecting system can easily swamp people with the sheer magnitude of the information volume involved. It is, therefore, essential that well-designed aids be developed to assist people in data interpretation in order to fully utilize the system and to permit realizing the potential benefits for real time action.

ADDENDUM TO 26 September 1975 IBOND Paper, "Proposed Recommended Guidelines for Future Development of Ocean Data Collecting Systems":

The concepts presented in the IBOND document, though directed to the marine environment, obviously also apply to land-based or unattended systems either afloat or ashore. It is assumed that the basic design permits a common design, and the subassemblies would employ modular construction, which readily permit adapting the completed package to the specifics of the location, whether manned or unmanned. It should be emphasized that no basic commitment is implied for utilizing any specific telecommunications system. Since modular construction, as mentioned, would be employed, it would be very practical to select the output interface module to satisfy the requirements of satellite, HF or microwave and solid wire telecommunications systems.

The following paragraph is copied from the IBOND paper and was designated Paragraph 1.5 of that document:

In order to minimize operating costs and to improve system reliability, it is strongly recommended that no maintenance or servicing be attempted on equipment when at sea. Technical service would only be supplied or utilized in port by trained personnel. This method significantly reduces both the initial investment and operating costs by minimizing the amount of electronic equipment spares required and further minimizes the amount of instruction or technical training needed since no seagoing personnel will be expected to do any maintenance or servicing.

The implications contained in the above paragraph were purposely minimized in the IBOND document but, for the present purposes, it appears appropriate to develop them further. Some of this is treated in earlier paragraphs but additional comment is perhaps appropriate. Due to the generally accepted poor reliability of marine and meteorological instruments, there has been no alternative but to support them with very costly logistics.

With the acquisition of more and more instruments for use in marine data collection programs, there has been a parallel increase in the total number of marine technicians and personnel required for maintenance, repair, and operation. It is becoming increasingly clear that the acquisition of an environmental measuring instrument tends to entail an increase in operating overhead for the period of its useful life. There is distinct evidence that this overhead figure is tending to become almost unmanageable. The overhead cost of instruments is essentially a hidden cost and, since it tends to increase over the years, it is not at all impossible for the "hidden costs" to exceed the amount of money available for new instrument acquisition.

Oceanographic research in particular, over the years, has proceeded to a high degree on a hand-to-mouth basis with little attention given to examining objectively the methods and related costs of using instruments. In view of the rapid and inexorable increases in the cost of using oceanographic instruments, it appears imperative to examine what we may do in order to improve the situation. A driving force in the consideration of oceanographic instruments is their constantly increasing complexity and sophistication. Unfortunately, this increasing complexity is not accompanied by increased reliability. It is evident, under the present trends, that instrument technicians will need steadily increased levels of training. This means that the financial investment in marine technicians will be steadily increasing. Considering the attrition rate of technicians and the need for more extensive training for recruits, the impact on budgets is predictable. On the plus side, the increasing sophistication of instruments which make use of rapidly advancing technology --- especially in electronics --- means that instruments are capable of

making more accurate and more rapid measurements of more parameters while the information output may be supplied in a computer compatible format. All of this is done with a generally declining cost per circuit. Unfortunately, the cost per instrument is constantly increasing, though the cost per circuit is decreasing since there are now many more circuits incorporated in one instrument. The above general changes in instruments, unaccompanied by a substantial increase in reliability, will force major changes in the way technicians are being used. These trends require significant increases for instrument maintenance and repair technicians. Importantly, some of the technicians will be needed on shipboard at sea where the increased numbers pose serious problems in the uses of discretionary ship space and contribute towards large cost increases.

Classical methods of handling instruments used in data collection leave much to be desired, especially when we consider the high cost of missed measurements. Missed measurements basically stem from instrument malfunction. Instruments may malfunction for many reasons, some of which are frequently obvious, especially after-the-fact, and some reasons may be quite obscure. In the final analysis, all instrument malfunctions are people related. The problems range from basically poor engineering on the part of the manufacturer to a moment of inattention on the part of a technician.

It would be considered an essential part of an efficient and smoothly operating data collection system to establish and maintain a continuous record of the performance of each instrument. This would include many details such as its calibration dates, stability of calibration and, in the event of any defects, a failure analysis record. Only by maintaining records of this sort can any idea be obtained as to technical weaknesses and general efficiency such as instrument utilization figures. Without maintaining records of this sort, it is almost impossible to head off any problems which show up in any given instrument design and especially to avoid problems in future procurement. While record keeping may appear to be unproductive from the administrative standpoint, it is vital to the successful continued operation of any data collecting system.

In view of the undoubted requirements for improvements in instrument reliability, and technical characteristics, it is apparent that at least a modest amount of R&D would be necessary for the development of satisfactory instruments for the proposed system. Throughout this document, there have been many references to the necessity of designing equipment with a high reliability. As mentioned in earlier paragraphs, this cannot be looked at as an isolated system parameter but rather must be examined in light of overall requirements. The problem, of course, is that improved reliability has a price tag and the selection of an optimum MTBF (Mean Time Between Failure) is an exceedingly important decision.

The following are excerpts from a document previously prepared dealing with this question:

I became involved with a similar problem a few years ago in connection with the manufacture of receiving equipment for shipboard use to obtain fixes from the Navy Navigation Satellite. We were faced with an exceedingly costly operation if we followed conventional methods, such as training engineers and technicians to maintain the equipment and to stock the necessary, very costly, spares on the various ships and shore-based establishments. I have data from an unpublished study, made at that time, which showed, rather convincingly, that very great sums of money would be saved if the policy were established that no spares would be purchased for use in shore facilities or aboard ship and no engineers or technicians would be trained for field repair and maintenance. This required that the Navy set up a small engineering support staff with minimum spares on the premises of the manufacturer. The spares and engineers were available on a moment's notice, 24 hours a day, to fly immediately wherever a ship was in order to effect necessary repairs. The entire operation could not even have been considered had the MTBF been a small number. The magic number which was selected was 5,000 hours which experience has shown was quite adequate and, fortunately, the equipment is now approaching, in actual use, a figure of 10,000 hours MTBF and has a rather enviable reputation for reliability. Something of this sort, at least in part, I feel can be very usefully employed in the area of oceanographic instrumentation. However, this would require almost industry-wide cooperation, etc. Therefore, there are considerable constraints as to how far one might reasonably expect to go in introducing significant changes. It would seem, however, that the present system is not working and that we can at least begin--and part of the key is how to begin--progress toward longer MTBF's. At present, to the best of my knowledge, there is no figure stated by any manufacturer of oceanographic instruments that can be used with any degree of confidence relating to MTBF.

In discussing the matter of not having spares at sea, it was very apparent from the academic research community that this would simply be intolerable and that technicians and spares must always go along with shipboard equipment. The basic point here was that the seagoing researcher did, in fact, accept and live with very significant amounts of instrument down time; however, since this was handled in the routine fashion by technicians and spares in order to get the instrument

repaired, there was no feeling of peer group pressure for not conducting the research in an accepted fashion. They felt this would not be the case if one were at sea with no spares and no technician when the instrument failed. The whole point here was that they had never had experience with high reliability instruments and equipment and did not properly appreciate the tradeoff. This particular policy, as mentioned, is a success -- not by virtue of the needs stated by the users, but by a command decision made at the funding level.

It should be apparent that with a reasonable MTBF, it may well be cheaper to take along complete instruments as spares rather than go to sea with spare parts for instruments. One point here is that, if one has spare parts, one needs technicians; also, if one has spare parts, the volume of space occupied by spares, as they are necessarily packaged, is usually significantly greater than that required for the complete instrument. This has a direct bearing on use on shipboard where space is restricted. Furthermore, this offers a greatly enhanced probability of getting all the required data.

In either manned or unmanned observing stations where data are especially critical and essential, it should be apparent that, with 100% redundancy in the data acquisition package the probability of lost data is exceedingly remote and almost unquestionably more remote than using conventional manned systems or "resident" technicians.

It is perhaps appropriate to suggest that the engineering and design of various hardware elements of the system should not be done by potential manufacturers. This may seem rather an undesirable constraint; however, the manufacturers are all too often highly biased and look forward to producing equipment that can utilize previously engineered or fabricated subsystems or elements. This means that, in fact, they tend to lack genuine objectivity in the instrument design. While it may be true that such a procedure may, on occasion, result in a satisfactory end product, it should be pointed out that this is, unfortunately, the exception.

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Submitted to:
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Princeton, New Jersey

OBSERVATION AND PREDICTION
OF OCEAN SPECTRAL WAVES

Technical Note No. 3

Project No. 6613

June 1976

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1.0 INTRODUCTION

To describe the "state of the sea" is to describe the total wave pattern at the ocean surface. At any place and time, the pattern is typically very complex and appears as an infinite number of individual wave components of different direction, amplitude and frequency. The total amount of energy accumulated in the composite wave motion (or sea state) is distributed over a wide range of frequencies.

For many years, mariners have been reporting sea state as a part of the synoptic ship report. The synoptic code provides for transmission of information describing direction, period and height of the most significant wind-wave and swell components. For about fifteen years, some of the larger forecast centers have been making routine numerical forecasts of significant wave parameters for distribution in a facsimile broadcast.

In the past two years, synoptic observation and prediction of more complete ocean wave spectra has become routine in the United States. The purpose of this paper is to present an overview of operational observation and forecasting of spectral ocean waves as now carried out on a synoptic basis. Optimum Track Ship Routing (OTSR), offshore drilling, deep-ocean mining and coastal engineering are but a few of the applications which require a complete specification of ocean wave spectra.

2.0 BACKGROUND

For purposes of clarity, we usually separate sea state into two general classes of waves. Waves which are still in the local wind-generating area are called "wind waves" or "sea". Waves that have traveled out of the generating area are known as "swell". Wind waves are typically irregular, chaotic, short-crested and difficult to predict. Swell waves are more regular, longer-crested and somewhat more predictable. On the borders of generating areas, neither term precisely describes the total sea state.

Surface wind speed is by far the most important parameter in controlling how high waves will grow; however, the length of time available for wave growth (duration) and the extent of the growth area (fetch) are factors which cannot be neglected. With a wind of constant velocity and sufficiently long fetch, seas continue to grow with time until a steady state is reached; the seas are then considered to be "fully developed" (for that wind condition).

There is considerable disagreement among various investigators concerning the length of time required to reach this steady state -- and on the fetch length required to achieve growth to the fully developed sea state. Figures 2-1a and 2-1b (from an article by Walden, 1961) show the growth of

Significant Wave Height ($H_{1/3}$) as a function of direction and the relationship between $H_{1/3}$ and fetch according to several different authors.

The function which mathematically describes the distribution of the square of the wave height as a function of frequency is called the "spectrum" of the wave motion. Since the square of the wave height is related to the potential energy of the sea surface, the same spectrum is also called the energy spectrum. If the individual components which comprise a composite pattern of a fully arisen sea at a given wind velocity are grouped around average frequencies (f_1) extending over small frequency ranges (Δf), the continuous distribution of an infinite number of components can be approximated by a finite number of components with different average frequencies. A series of sine waves can then be considered as "filtered out" of the total sum and their individual characteristics are approximated by the average frequency, f ; period, T ; wave length, L ; and the average wave amplitude. If rectangles whose areas are equal to the squares of the amplitudes $[A(f)]^2$ are plotted against the average frequency, f , we obtain a good approximation to the wave energy spectrum (Figure 2-2).

As wind speed increases, the area under the curve increases, and the maximum spectral energy shifts from higher to lower frequencies. As in the case for duration and fetch, researchers disagree concerning the frequency of maximum spectral energy

Figure 2-1(a)

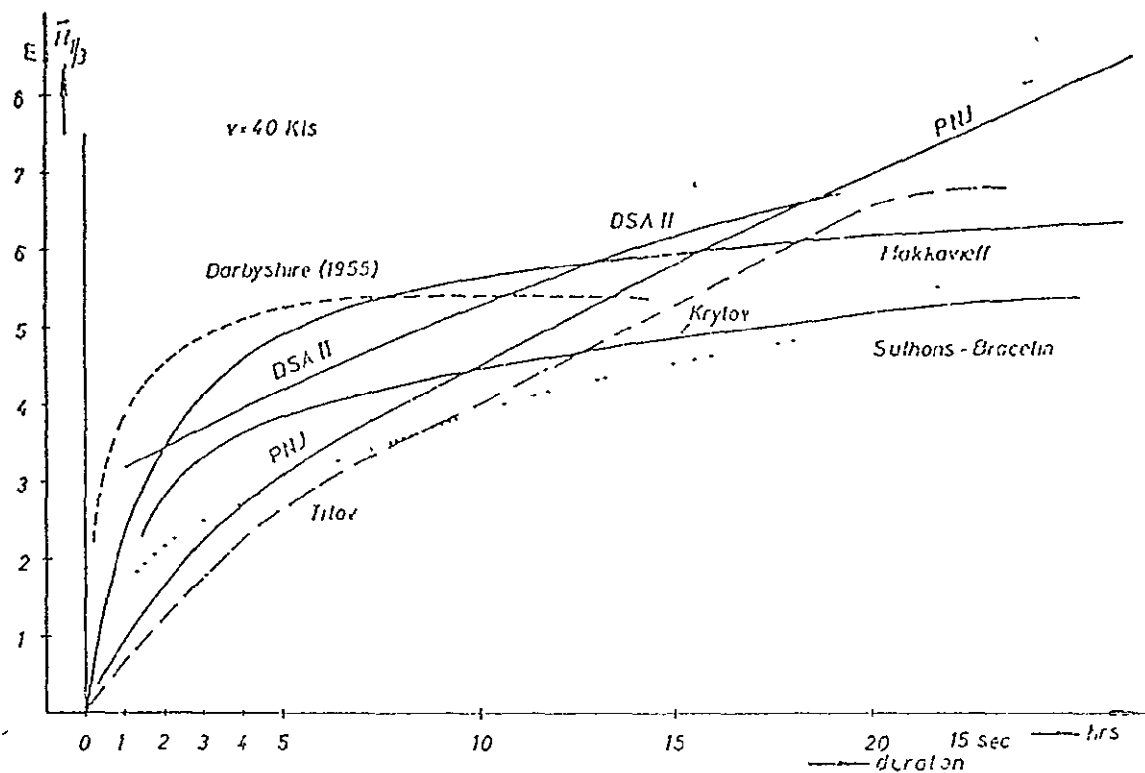
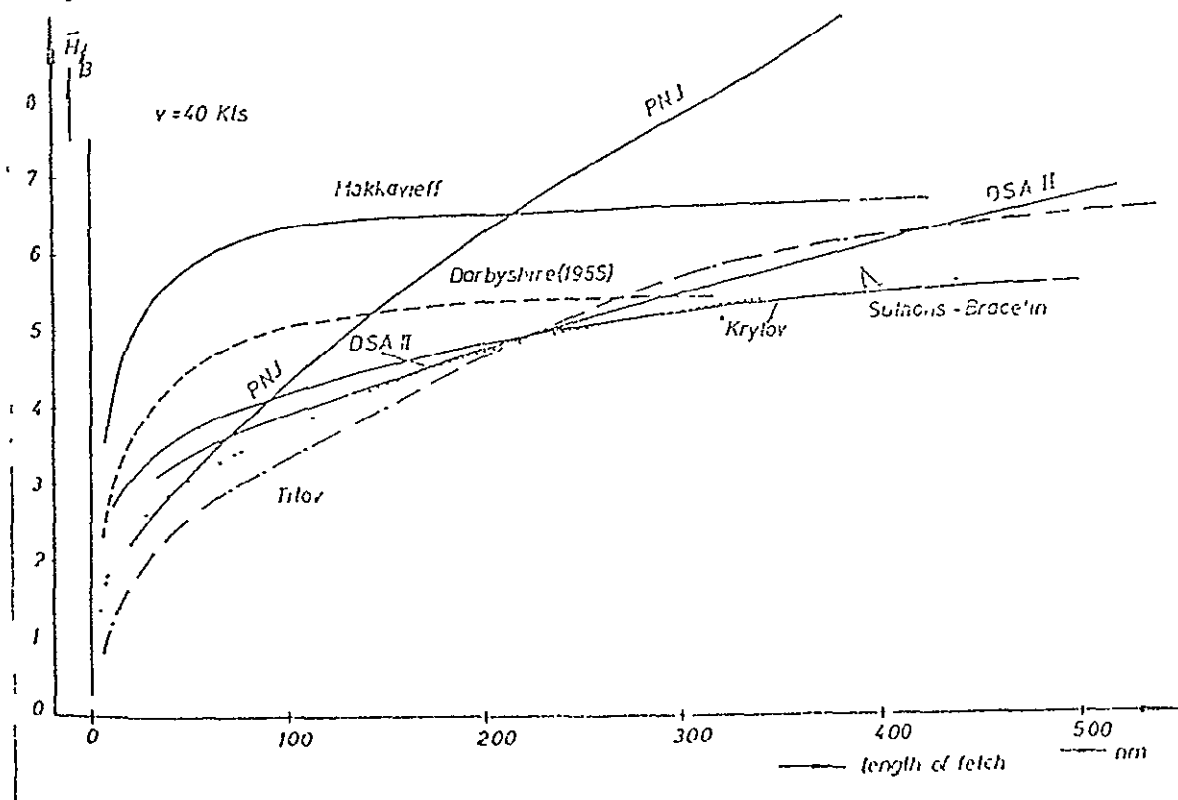


Figure 2-1(b)



Figures 2-1(a) and (b). Significant Wave Height ($H_{1/3}$) as functions of Duration and Fetch According to Various Researchers. Wind Speed 40 knots. (From Walden, 1961).

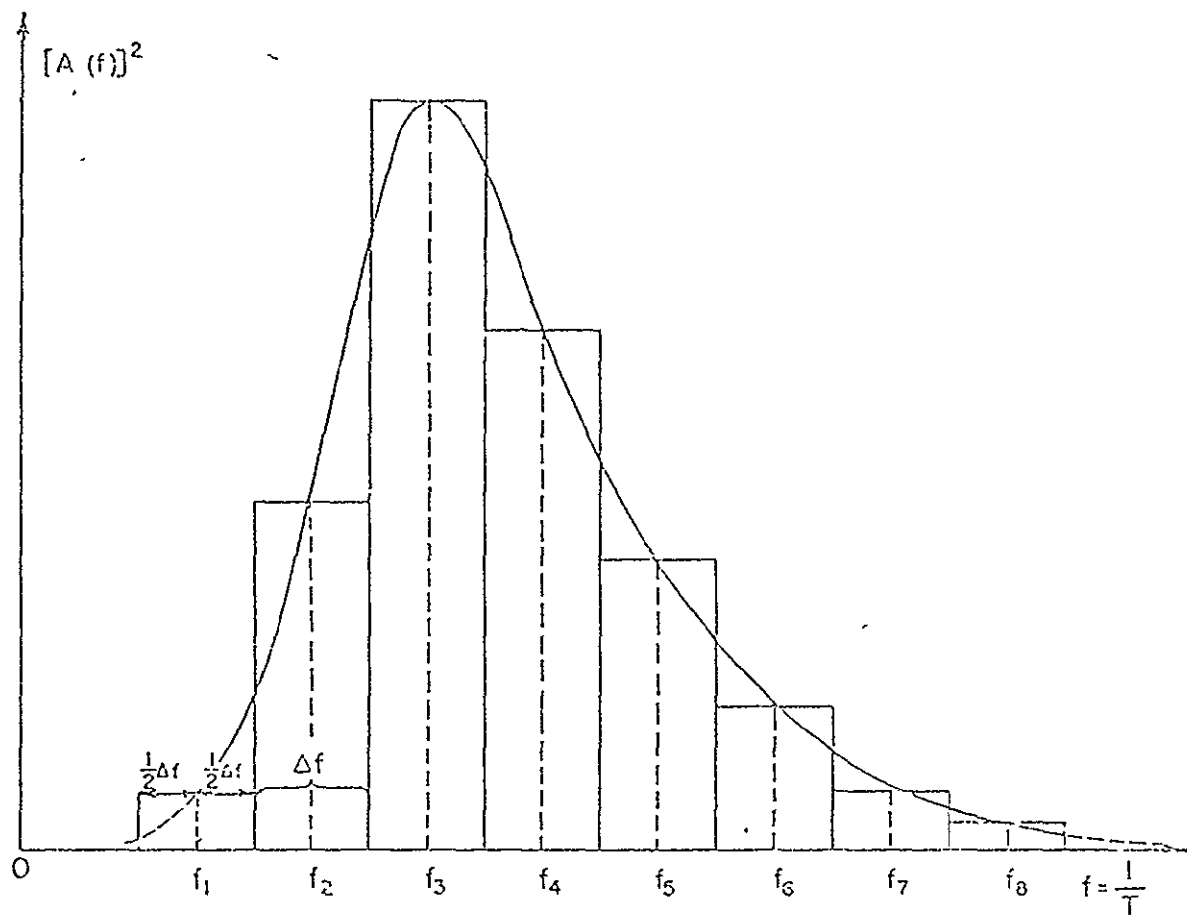


Figure 2-2. Typical Finite - Difference Approximation To
The Wave Spectrum (from Pierson, Neuman, and James, 1955).

and the total energy which results from a steady state wind. Figure 2-3 (also taken from Walden, 1961 in Ocean Wave Spectra) points out the difference in shape of observed and theoretical spectral curves for wind speeds of 60 knots.

Since various authors use different nomenclature to describe the same features in wave spectra, it is often confusing to compare results. Table 2-1 (from Dorrestein, 1961 in Ocean Wave Spectra) is reproduced as a convenient summary of the terms associated with these authors.

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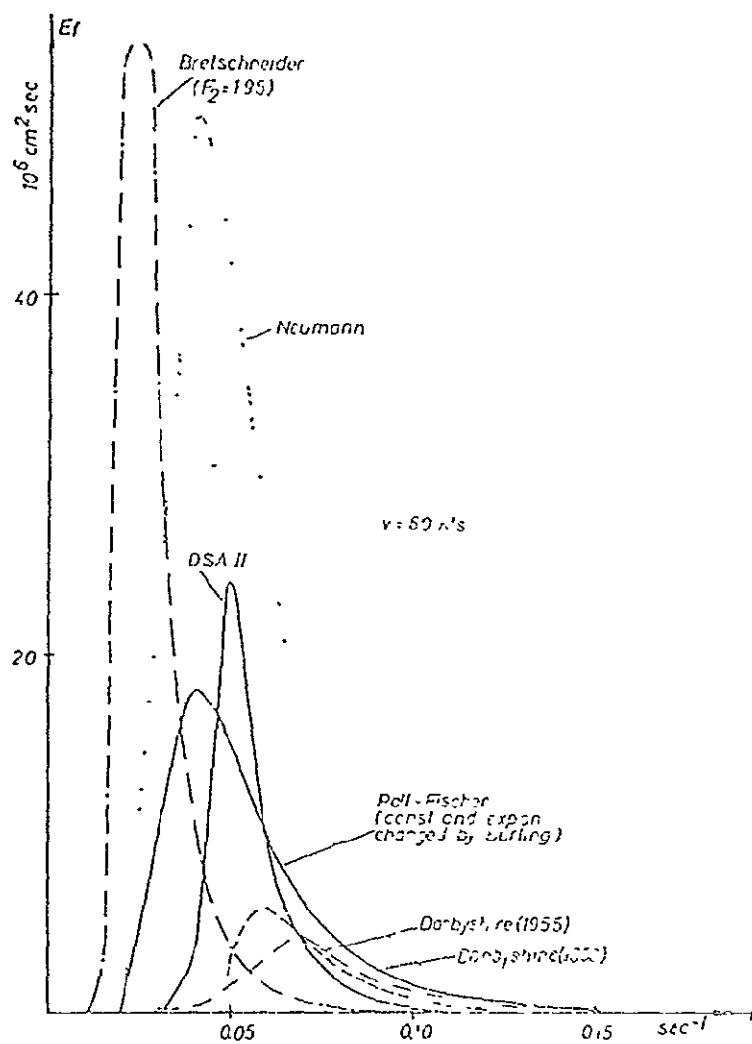


Figure 2-3. Various Wave Spectra for Fully Arisen Seas
with a Wind Speed of 60 Knots (from Walden, 1961)

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Table 2-1. One-Dimensional Wave Spectra Nomenclatures Used by Various Authors. (from Dorrestein, 1961).

ONE-DIMENSIONAL WAVE SPECTRA NOMENCLATURES USED BY VARIOUS AUTHORS <i>R. Dorrestein</i>		
Kon. Nederl. Meteorologisch Inst., De Bilt, The Netherlands		
Say σ^2 = mean-square deviation of sea elevation from its mean (recommended unit m^2 or cm^2)		
If spectrum narrow (Rayleigh distribution for extremity), mean-square wave height \overline{H}^2 = approx $8\sigma^2$.		
Then wave energy density is $g\rho\sigma^2$ = approx $\frac{1}{2}g\rho\overline{H}^2$ (unit $\frac{\text{Joule}}{m^2}$)		
Recommendation: use as abscissa of spectral curve f = cycles per sec exclusively (Breitschneider also uses this symbol.)		
Author(s)	Ordinates of spectral curve	Integral of spectrum
Burgess use	$H(f)$ = contribution to rms deviation per unit f	σ^2
Neumann,	$E_f = 2W(f)$	$E = 2\sigma^2$
Walden also use	(Walden denotes this by $\frac{H_f^2}{4}$)	
Dorrestein use	H_f^2 = (by definition) $4E_f$ = $8W(f)$	$H^2 = 4E = 8\sigma^2$
Breitschneider uses	$S_H(f)$ = (by definition) $4E_f$ = $8W(f)$	$\int_0^\infty S_H(f) df = 8\sigma^2$
	Wave energy density per unit f	Total wave energy density
Neumann	$g\rho H(f)$	$g\rho\sigma^2$
Dorrestein & Walden	$\frac{1}{2}g\rho E_f$ $\frac{1}{2}g\rho H_f^2$	$\frac{1}{2}g\rho E$ $\frac{1}{2}g\rho H^2$
Breitschneider	$\frac{1}{2}g\rho S_H(f)$	$\frac{1}{2}g\rho \int_0^\infty S_H(f) df$
Express H_{den}^2 for "significant" height for relatively narrow spectrum $H_{den}^2 = 16.0\sigma^2 = 8.0E = 2.0\overline{H}^2$		

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3.0 SYNOPTIC SPECTRAL WAVE OBSERVATIONS

A number of spectral wave observations have been made using pressure sensors, wave staffs, accelerometer systems, etc. In general, these have not been made available for international distribution on a truly synoptic time schedule. On 3 December 1974, the NOAA Data Buoy Office (NDBO) in the United States deployed a large discus buoy in the Gulf of Alaska near 56.0N and 147.9W. This buoy was equipped with an advanced Wave Measurement (WM) system designed to observe and report spectral wave data on a synoptic schedule.

The wave measurement system consists of a rigidly mounted accelerometer with its sensitive axis parallel to the buoy's vertical center line. An onboard computer computes covariances formed from a series of digital samples at discrete intervals. These covariances are then transmitted to a shore communication station where a second computer generates spectral densities at fifty frequency intervals. These spectral densities as well as the significant wave height are entered immediately into Global Telecommunication Service (GTS) circuits every three hours for national and international relay. The buoy in the Gulf of Alaska has been transmitting spectral data continuously for a period of over nine months. A similar system was deployed off the U.S. East Coast near 36.5N and 73.5 W on 6 December 1974. A number of synoptic reports were also received from this Wave Measurement system before the buoy developed electronic problems and was eventually disabled by a ship collision.

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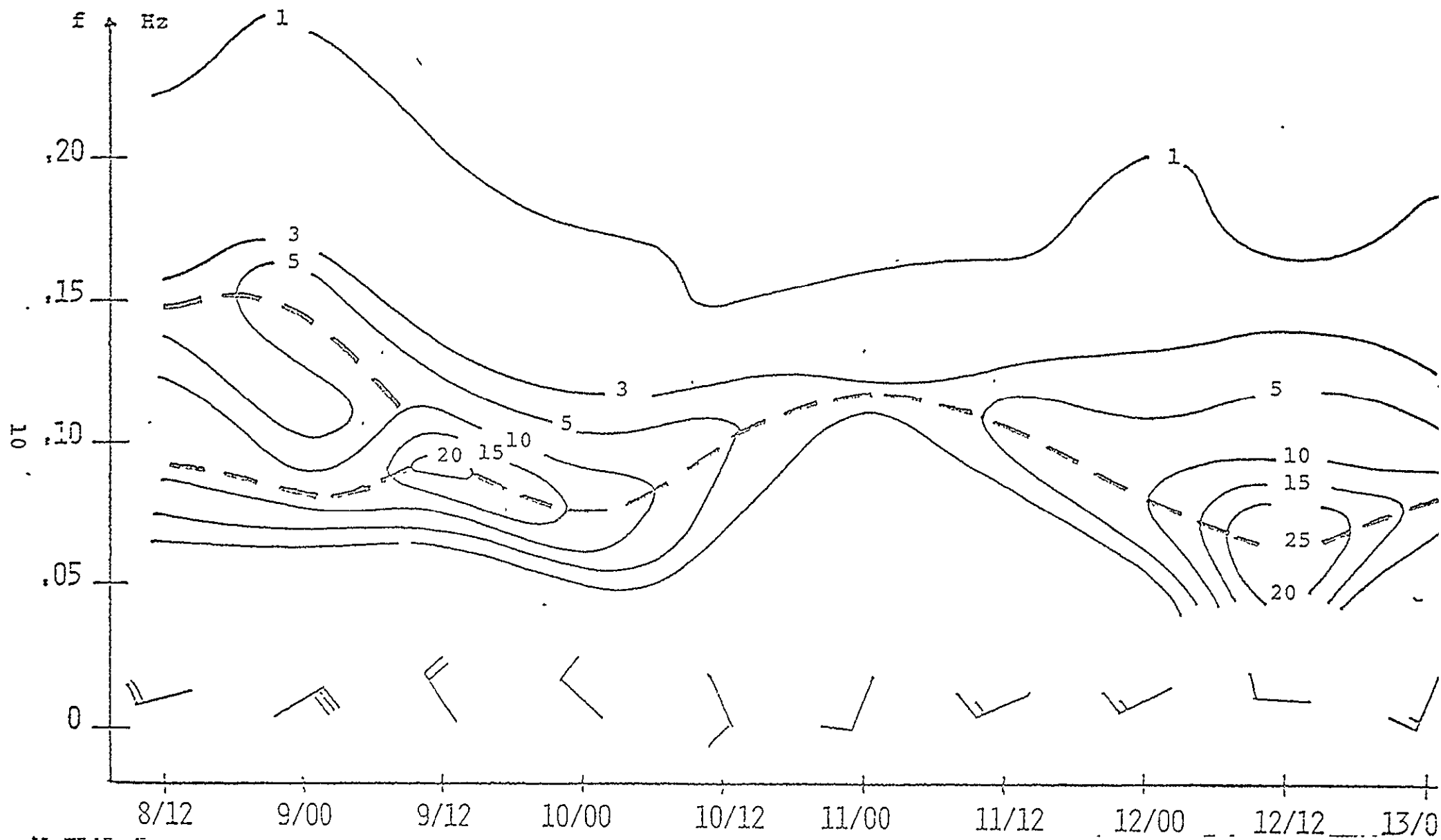


FIGURE 3-1a: TIME SERIES ANALYSIS OF SPECTRAL DENSITY at EB03 (56.0N, 147.9W) from 081200 GMT to 130000 GMT December 1974. Density contours (M^2/Hz). Heavy dashed lines show maximum frequency.

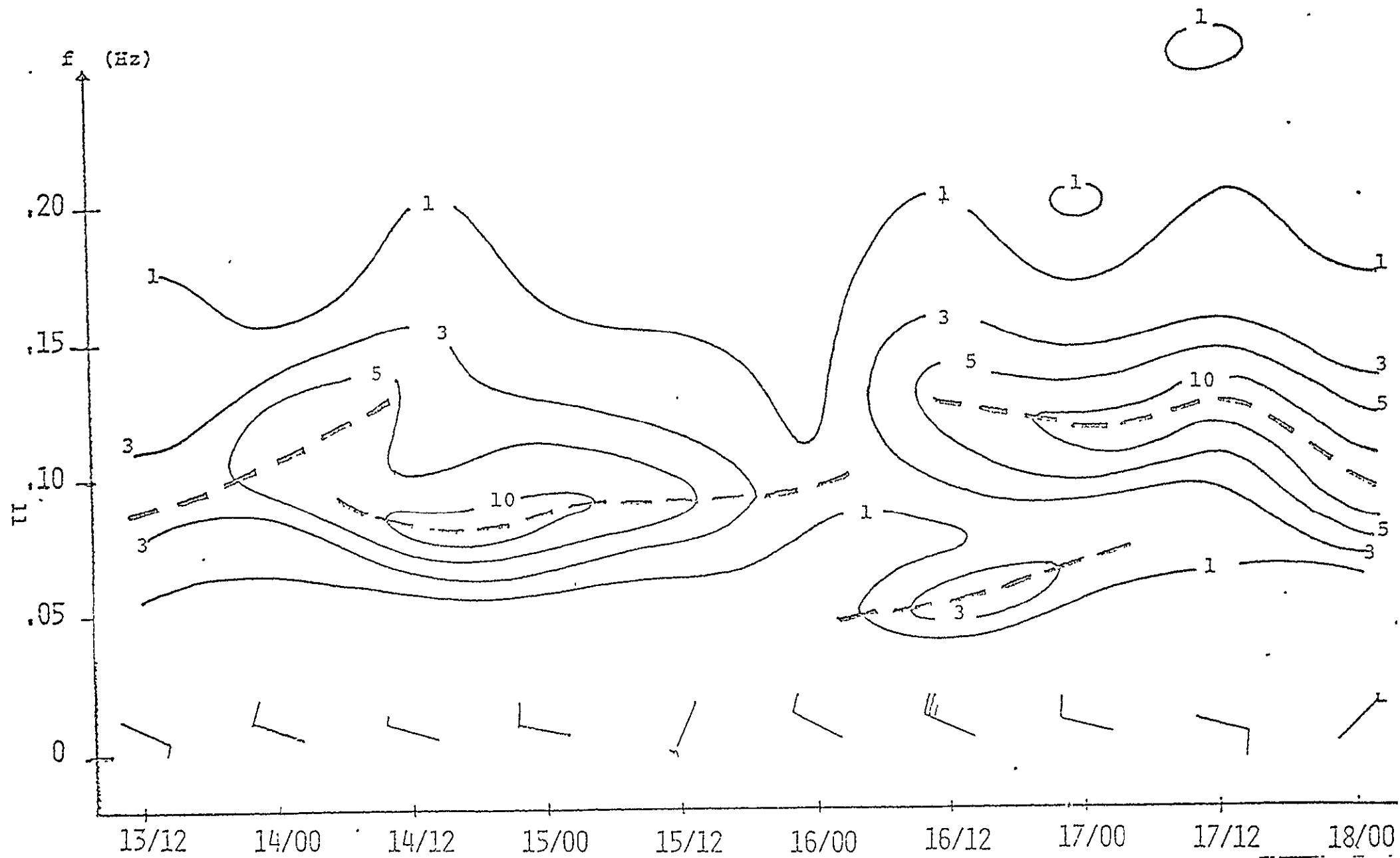


FIGURE 3-1b: Same as 3-1a for 131200 GMT to 130000 GMT December 1974.

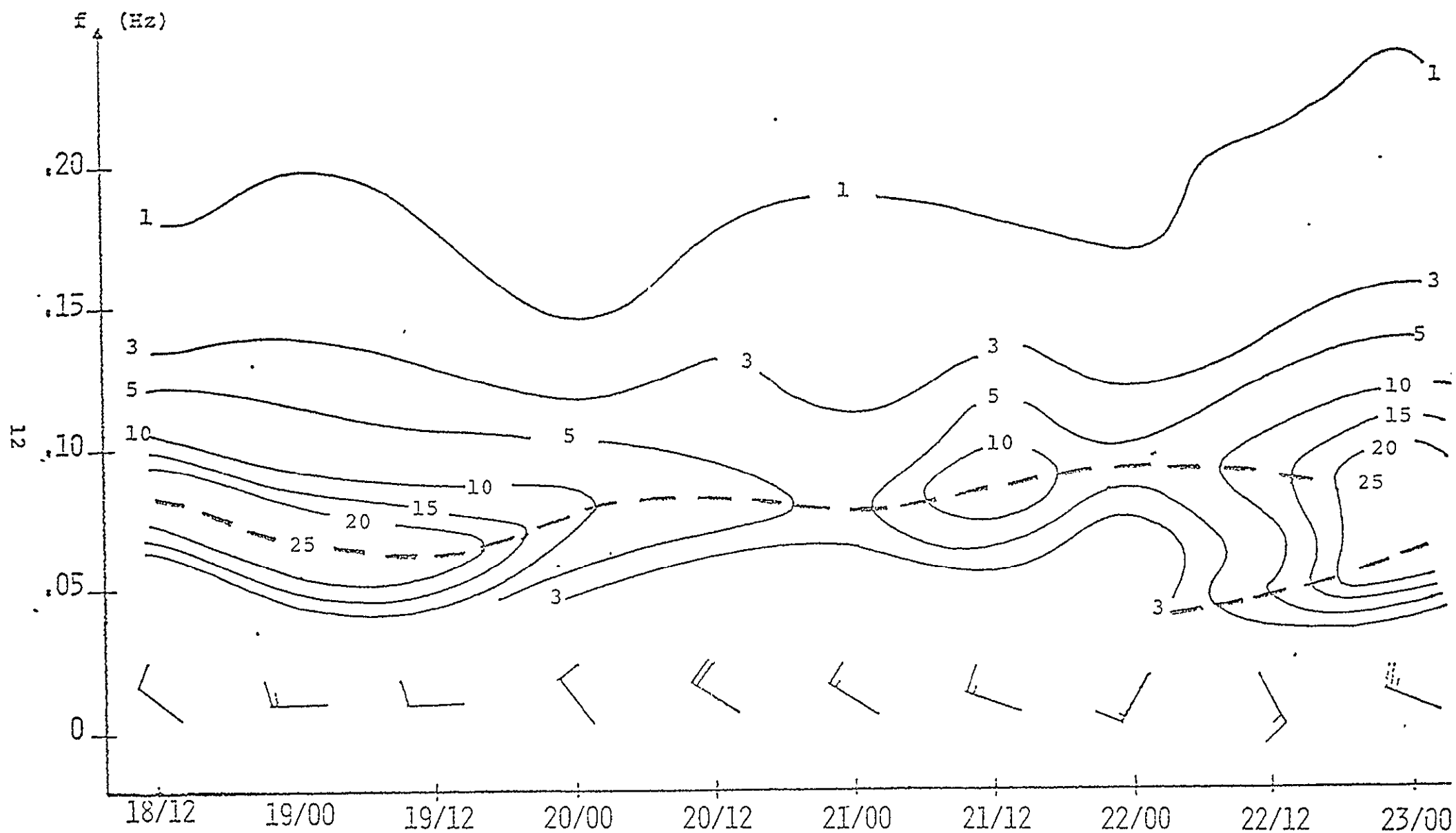


FIGURE 3-1c: Same as 3-1a for 181200 GMT to 230000 GMT December 1974.

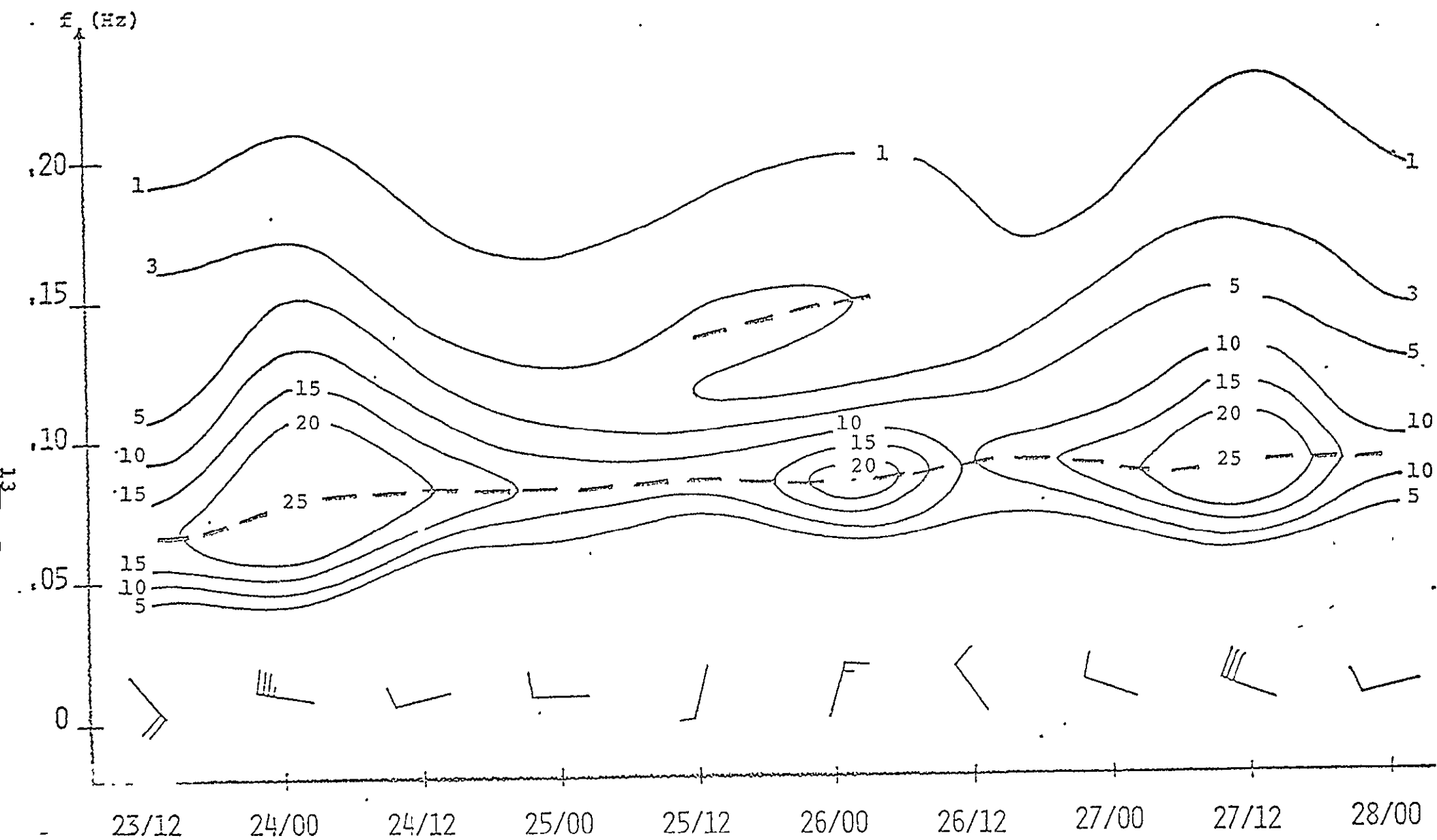


FIGURE 3-1d: Same as 3-1a for 231200 GMT to 280000 GMT December 1974.

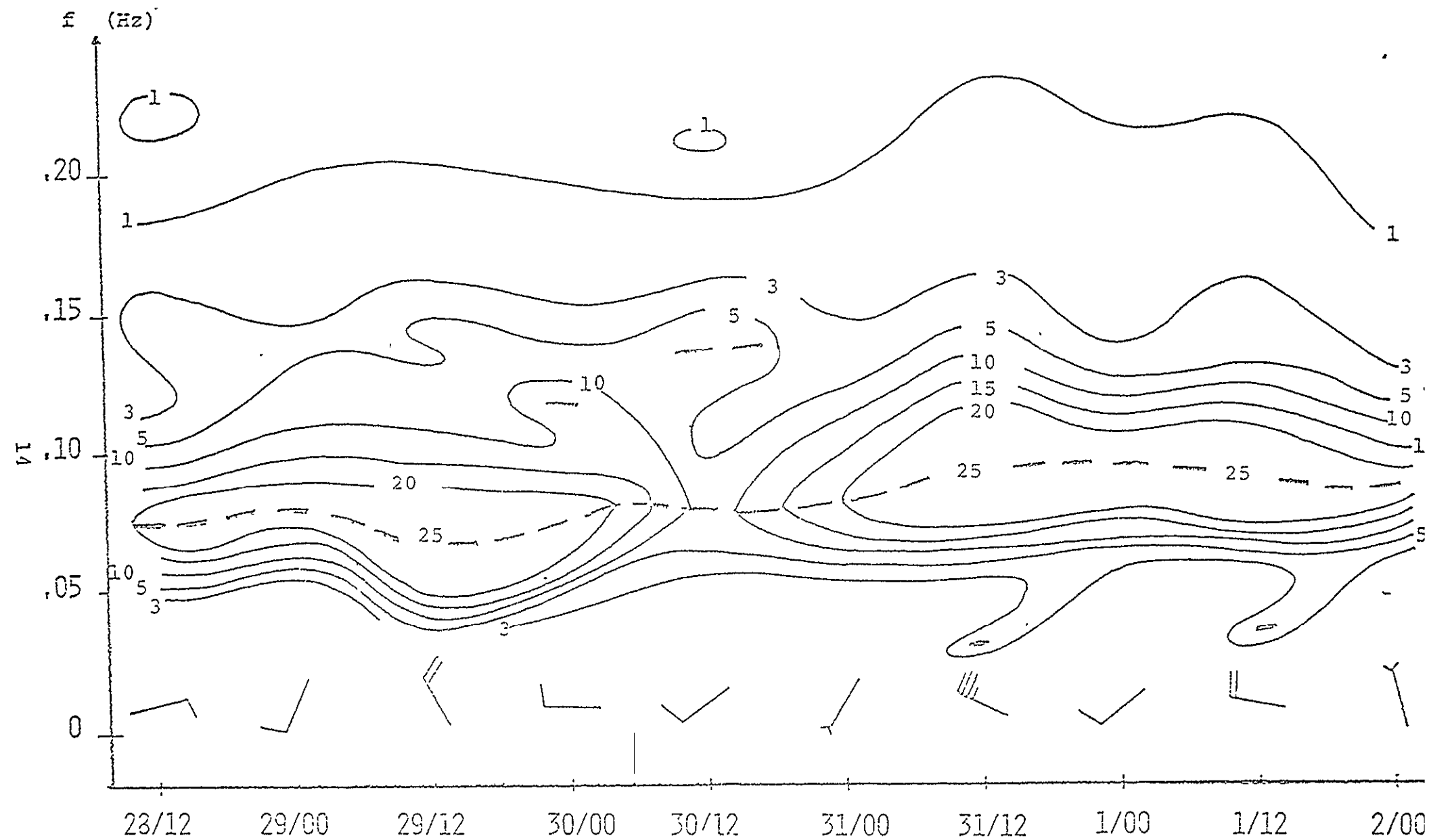


FIGURE 3-1c. Same as 3-1a for 261200 GMT December 1974 to 020000 GMT January 1975.

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Figures 3-1(a) through (e) show an analysis of spectral density (meters²/Hertz) as a function of frequency (f in Hertz) and time at buoy EB03 in the Gulf of Alaska. The thin solid lines are contours of spectral density level while the heavy dashed lines show the frequency of maximum energy. Local wind speed and direction are shown by conventional wind barbs (knots). It is obvious that a smooth contour pattern can be drawn and that this buoy is dominated by longer-period swell from distant sources.

Figures 3-2(a) through (e) show a similar analysis of spectral density measurements from buoy EB01 in the Atlantic. This location is obviously fetch limited and not so well exposed to distant swell. Locally-generated wind waves at higher frequencies are more common here. These plots are typical of the excellent continuity shown by these new systems; they are all the more valuable because the reports are available in less than two hours after observation time.

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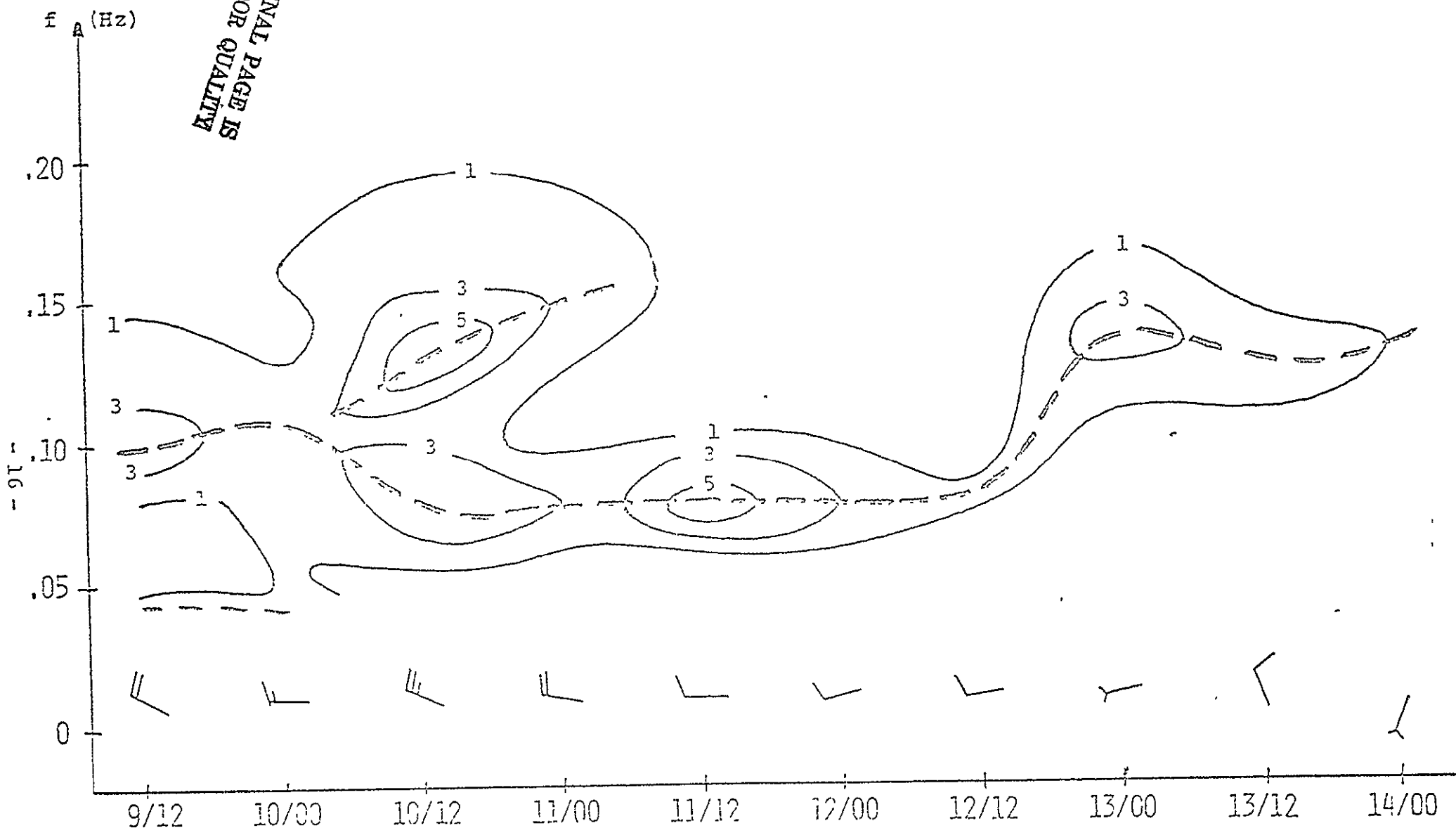


FIGURE 3-2a: SPECTRAL DENSITY TIME SERIES FOR EB01 from 091200 GMT to 140000 GMT December 1974. Thin, solid lines are contours of spectral density ($1^2/\text{Hz}$). Thick, dashed lines show frequency (f in Hz) of maximum density. Winds are in knots.

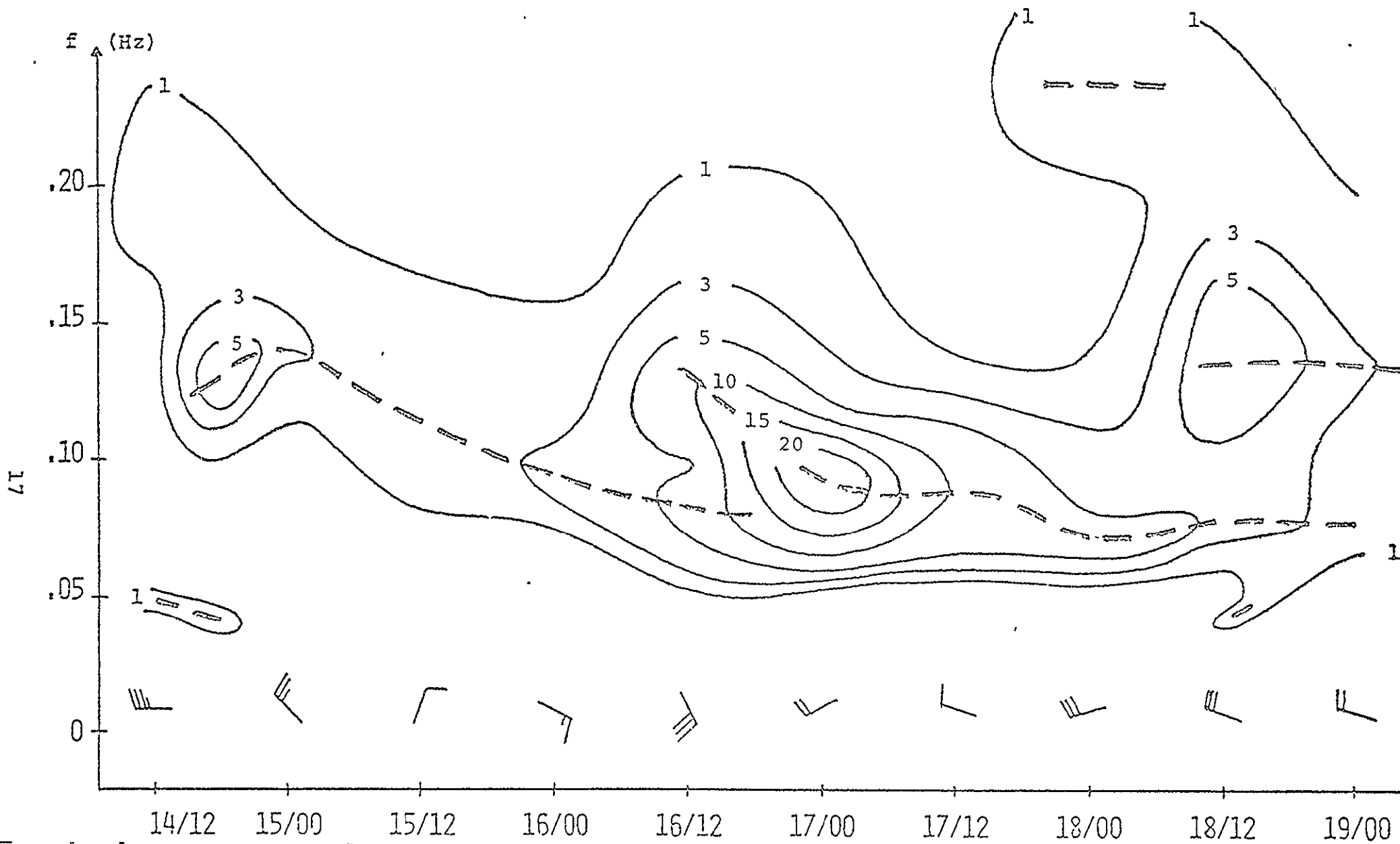


FIGURE 3-2b: Same as 3-2a for 141200 GMT to 190000 GMT December 1974.

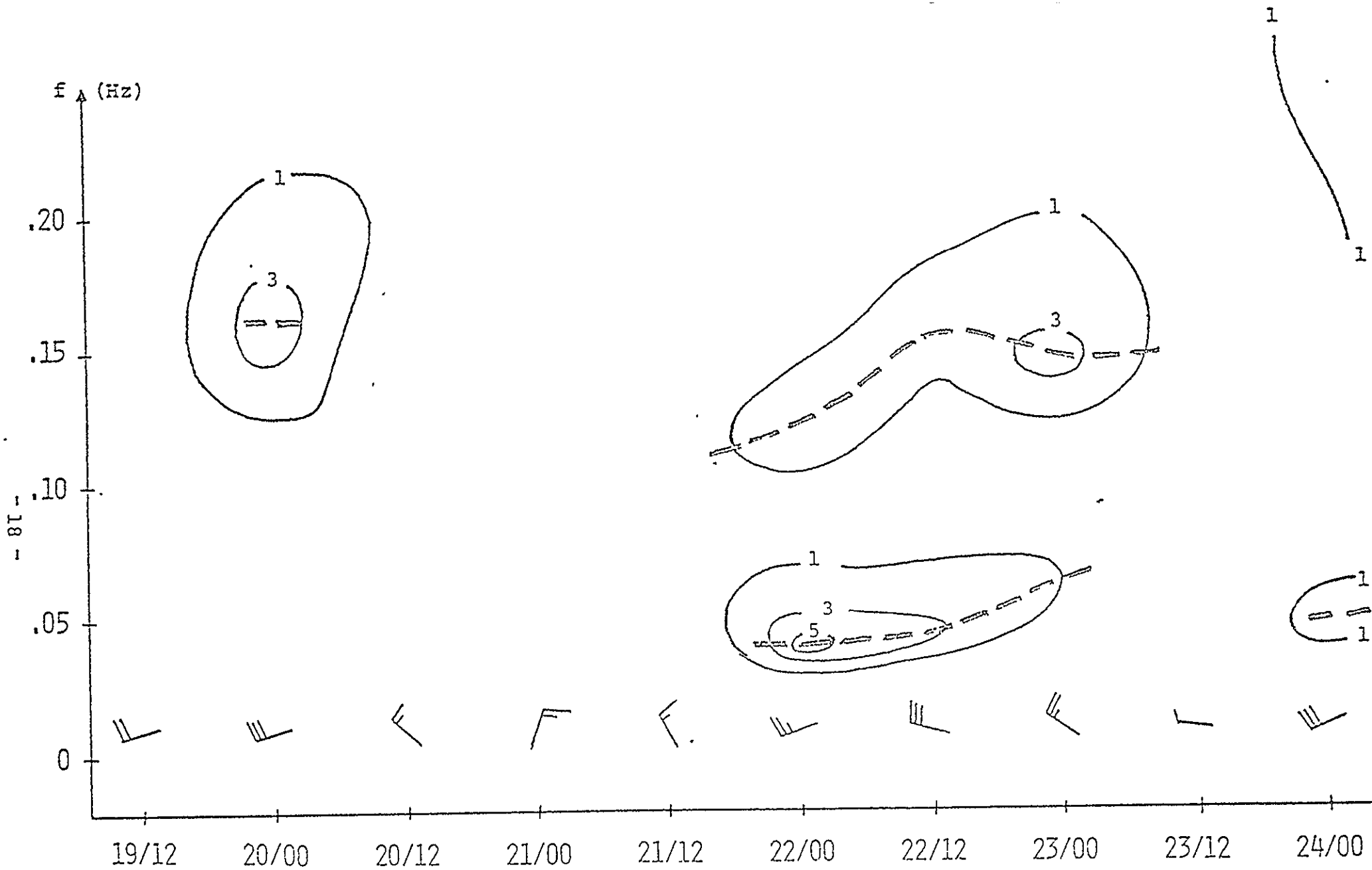


FIGURE 3-2c: Same as 3-2a for 191200 GMT to 240000 GMT December 1974.

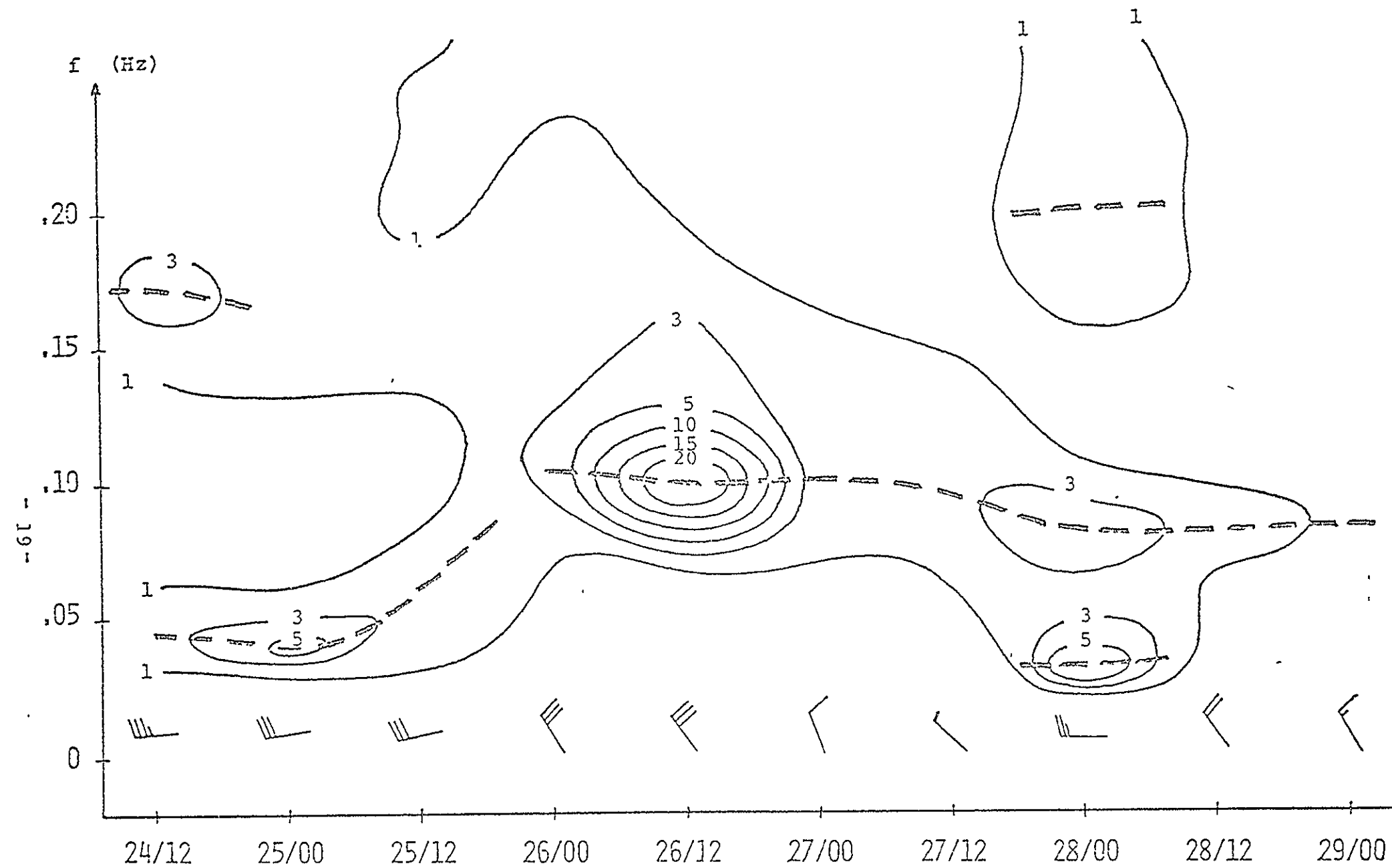


FIGURE 3-2d: Same as 3-2a for 241200 GMT to 290000 GMT December 1974.

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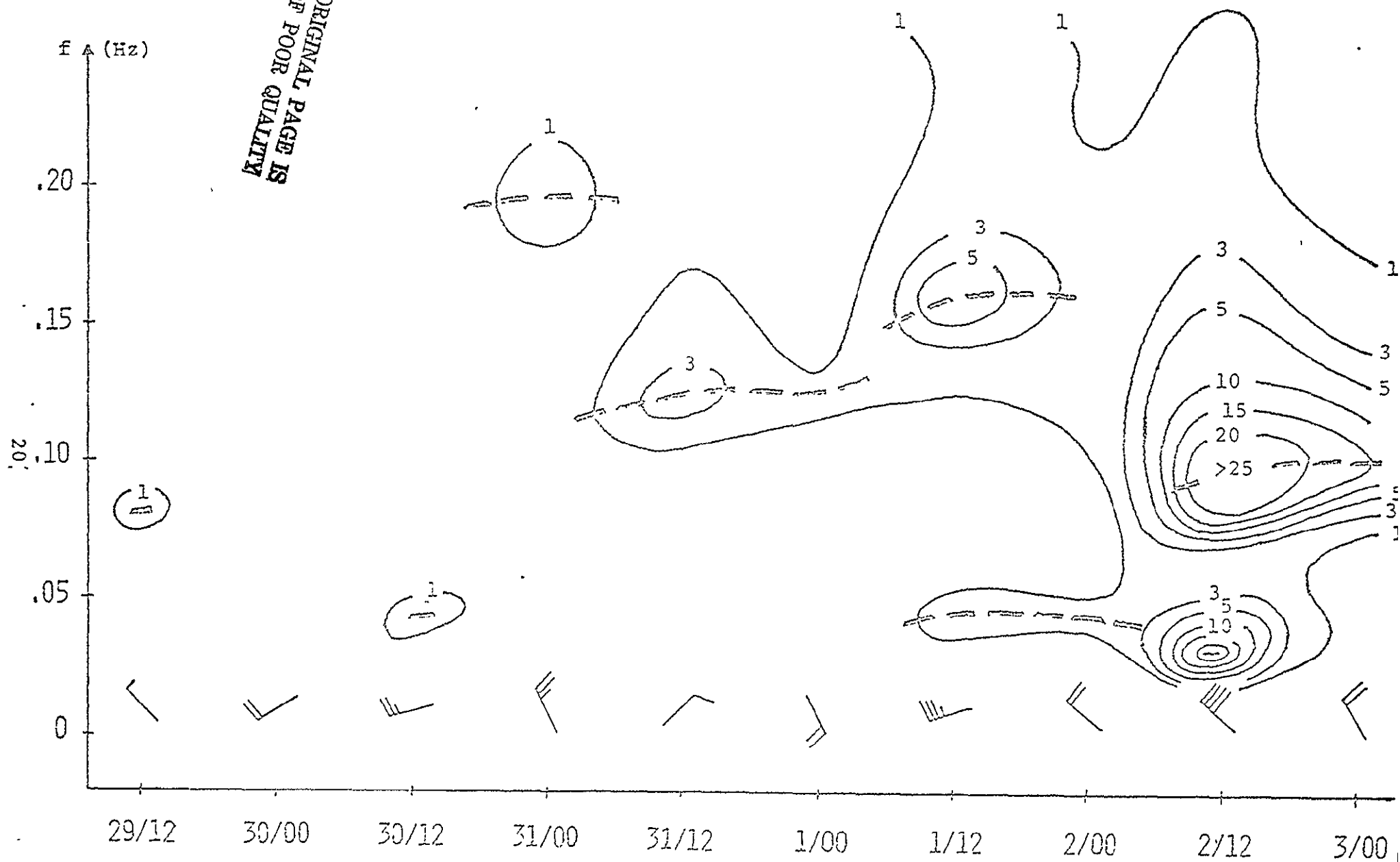


FIGURE 3-2e: Same as 3-2a for 291200 GMT December 1974 to 030000 GMT January 1975.

4.0 SPECTRAL WAVE MODELS

Due to the increasing demands from government and commercial interests, rapid development has occurred in the operational prediction of sea state. Because of the complexity and magnitude of the effort involved in making wave forecasts for large ocean areas, numerical methods have been applied to solution of the problem. In general, two basic types of wave models have been used - singular models and spectral models. The former attempt to predict the space/time distribution of the most significant component(s) without treating the complete growth, decay, transfer and propagation functions associated with a large number of components.

Wave models which attempt to predict the form of the energy spectrum throughout the time/space domain are commonly known as "spectral" models. The general approach in these models is to decompose the observable composite waves into a set of discrete components to calculate the growth, decay, transfer and propagation of the energy in each component along several directions, and then, by statistical inference, to derive the composite wave parameters.

Spectral models make use of the basic energy balance equation:

$$\frac{\partial E(f, \theta)}{\partial t} = -Wg \cdot VL(f, \theta) = S(f, \theta) \quad (1)$$

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where $E(f, \theta)$ is wave energy density of the spectral component at frequency f and direction θ at any space-time position, Wg is the deep water group velocity appropriate to that component, and $S(f, \theta)$ is the sum of all sources and sinks of energy for each component, i.e., the growth/decay terms. The major differences among the numerous models which have been used for numerical prediction depend upon (a) whether the S function in (1) is empirical or theoretical, (b) how propagation (the $-Wg \cdot \nabla E$ term) is affected and (c) whether the model treats processes such as wave breaking and non-linear wave-wave interaction. A general outline of the most well-known numerical wave models has been prepared by Dexter (1973).

The Australian Bureau of Meteorology has carried out a series of comparative tests for four different numerical models (Dexter, 1974):

- a. A singular model adaptation by Trajer (1966) of the numerical "wave ray" approach of Wilson (1961, 1963).
- b. An empirical spectral model designed by Dexter (1974) which uses the fully-developed spectrum of Pierson and Moskowitz (1964) together with angular spreading by Neumann (1952) and an empirical dissipation function due to Bunting (1966).
- c. The theoretical spectral model of Inoue (1967).
- d. The model of Barnett (1968) with minor modifications to the growth and damping terms.

In essence, the tests showed close agreement in most respects. The differences were less than errors to be expected through use of incorrectly specified marine wind fields as the model driver.

Other spectral models which have had wide operational use include the French Spectroangular models described by Gelci et al (1957) and Fons (1966), the Mediterranean adaptation of the Pierson-Moskowitz approach described by Lazanoff et al (1973) and the Fleet Numerical Weather Central (FNWC) version of the Pierson/NIU model. All of these models have shown considerable improvement over the singular models used earlier for operational prediction of significant wave height ($H_{1/3}$).

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5.0 SYNOPTIC SPECTRAL WAVE PREDICTION

Two different versions of the Pierson/NYU approach are being used for synoptic spectral wave prediction in the United States. One is based upon a rectangular grid system on a Lambert conformal projection and is used only for limited areas where long-distance propagation is not a major factor. The largest model covers all of the Northern Hemisphere and part of the Southern Hemisphere and is based upon an icosahedral gnomonic projection. Fourteen of the twenty hexagonal subprojections needed to cover the globe are now being subjected to synoptic computation. Each subprojection has 325 grid points; a special orientation scheme was chosen to place as many vertices as possible over land and to place edges over land/ocean boundaries. This projection was selected for operational use because great circle segments are represented as straight lines.

Both of the models described above treat 12 directional and 15 frequency components at each grid point. The time step is three hours, but until August 1974 the wind field was held constant for two time steps (6 hours). The center frequency, center period and bandwidth of the fifteen frequency bands are shown in Table 5-1.

Table 5-1: Center Frequencies, Periods and Bandwidths in
the FNWC Spectral Ocean Wave Model.

BAND	FREQ (Hz)	PERIOD (Sec)	BANDWIDTH (Hz)
1	.03889	25.7	.005556
2	.04444	22.5	.005556
3	.05000	20.0	.005556
4	.05556	18.0	.005556
5	.06111	16.4	.005556
6	.06667	15.0	.005556
7	.07222	13.8	.005556
8	.07778	12.8	.005556
9	.08333	12.0	.005556
10	.09167	10.9	.011111
11	.10278	9.7	.011111
12	.11667	8.6	.01667
13	.13333	7.5	.01667
14	.15278	6.5	.02222
15	.16393	6.1	.10000

Six-hourly (scheduled to become 3-hourly) Marine Wind analyses are used to maintain spectral continuity in the analysis mode. A Planetary Boundary Layer diagnostic model is used to derive forecast marine winds from an Atmospheric Primitive Equation (PE) model. PNWC runs the model to 72 hours twice daily requiring a computational capacity of approximately 1.8 Million Instructions Per Second (MIPS) to achieve a throughput rate of 30 minutes per forecast day. Outputs include a complete frequency/direction spectrum (spectral densities) at any designated grid point, total energies in any frequency or direction band, significant wave height and percentage of whitecaps. Significant wave height fields are machine contoured for transmission by computer-driven radio facsimile while spectral data are disseminated in the form of addressed messages.

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6.0 SPECTRAL MODEL VERIFICATION

The NDBO buoy-mounted spectral wave measurement systems described in Section 3.0 provide an excellent mechanism for routine verification of spectral wave forecasts. Figure 6-1 is a scatter diagram of FNWC versus EB03 Significant Wave Heights ($H_{1/3}$) for January and February 1975. EB03 is the buoy located in the Gulf of Alaska which has good exposure to swell from storms throughout the North Pacific.

Numerous individual FNWC and EB03 spectral distributions have been compared. They vary from nearly perfect agreement to an occasional case where the comparison is rather poor. In the latter instances, one can invariably trace the cause to an incorrect specification of the marine wind fields used to drive the spectral forecast model (due either to sparse data at analysis time or an erroneous Primitive Equation forecast).

Figures 6-2 and 6-3 show the mean spectral density distribution as a function of frequency for FNWC and EB03 during January and February 1975. The FNWC Spectral Ocean Wave Model is obviously generating more energy in the center of the spectrum than is being measured by the buoy. It is believed that holding the marine winds constant for two time steps (6 hours) contributes to excessive growth. Wind fields are now being generated at 3-hourly intervals and further

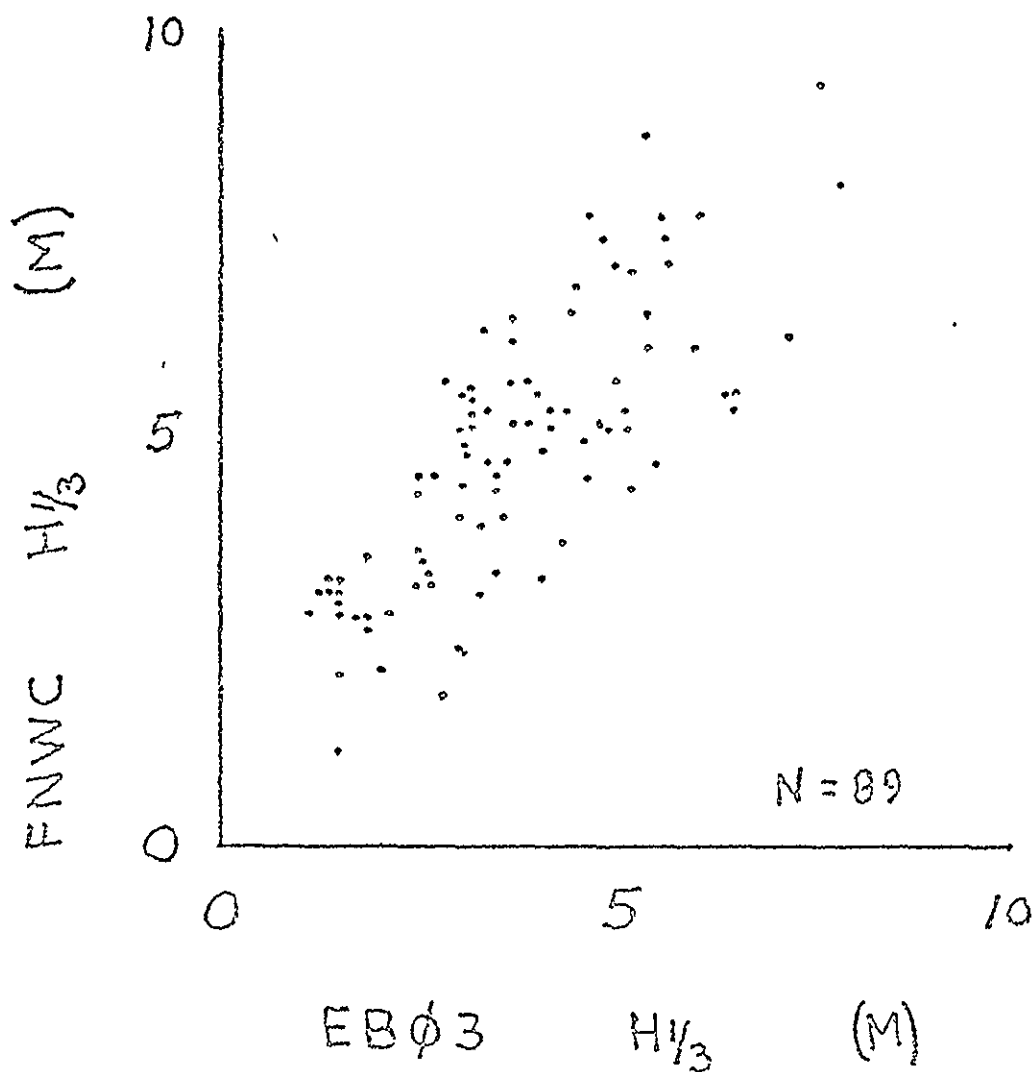


FIGURE 6-1: Scatter Diagram of FNWC Versus EB03
Significant Wave Heights for January and February 1975.

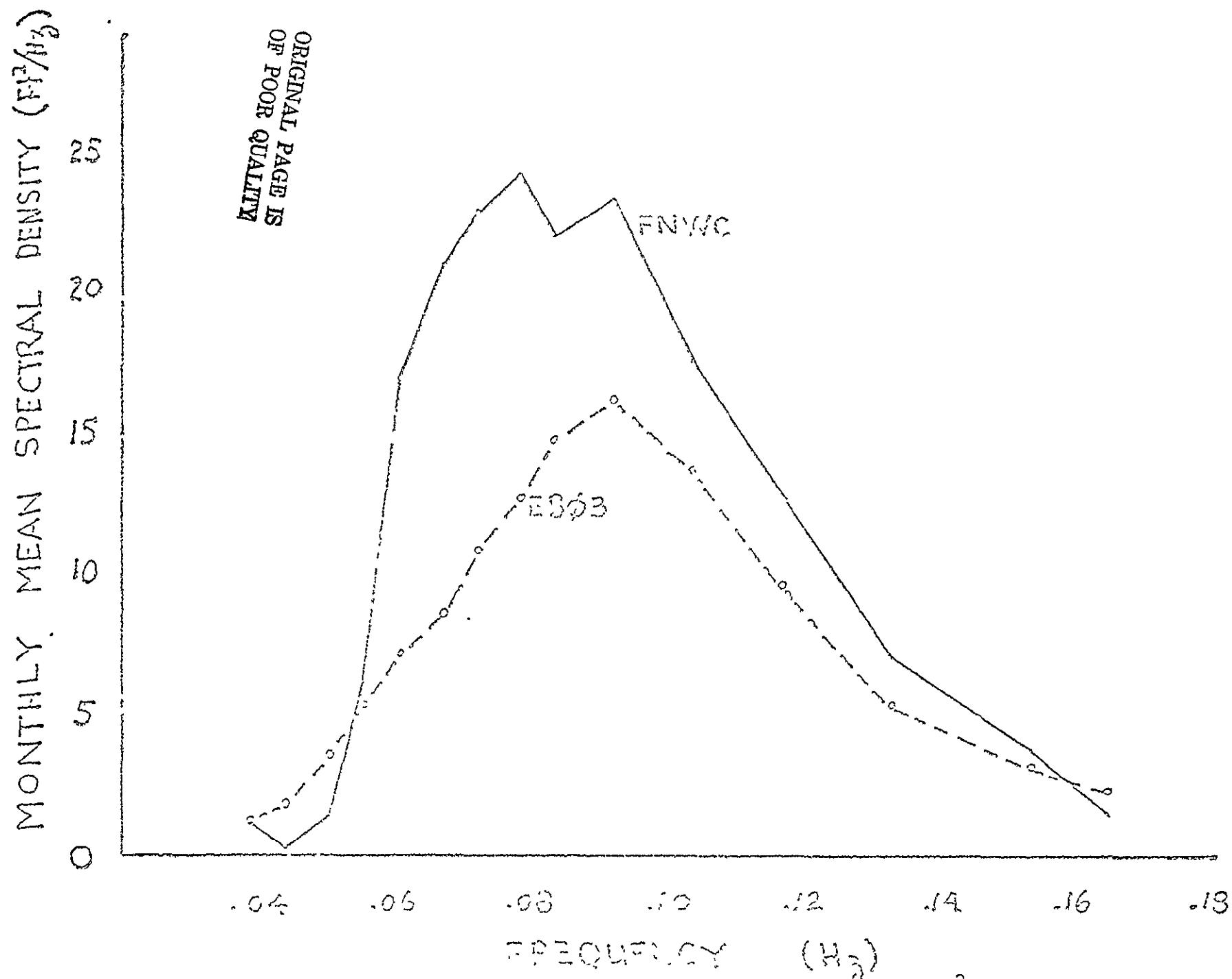


FIGURE C-2: Distribution of Mean Spectral Density (ft^2/Hz)
with Frequency (Hz) for January 1973.
FNWC (solid line), ESQ3 (dashed line)

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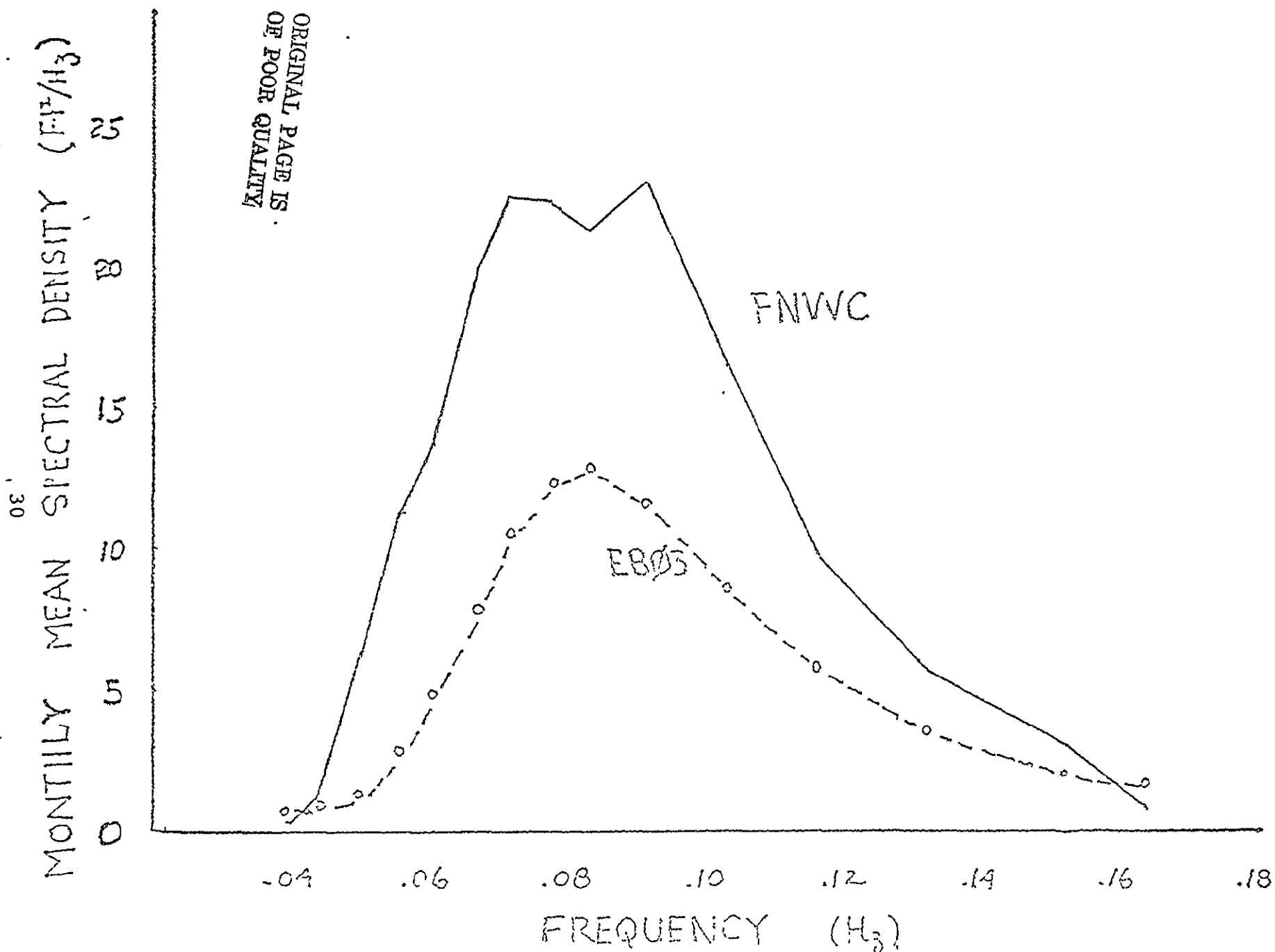


FIGURE 6-3: Distribution of Mean Spectral Density (Ft^2/Hz)
With Frequency (Hz) for February 1975.
FNVWC (solid line), EB03 (dashed line)

verification work is in progress to determine if model energies are still systematically too high. In spite of the observed errors, the spectral approach has led to a distinct improvement in ocean wave prediction. Not only are significant wave height forecasts better, the user now has spectral energy distributions to support those applications which are direction and/or frequency sensitive.

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7.0 FUTURE PLANS/REQUIREMENTS

FNWC has outlined specifications for a global spectral wave model with 15 frequencies, 24 directions and a mesh length of 90 nautical miles. It is estimated that a computer capacity of nearly 50 MIPS will be required to make synoptic forecasts at 30 minutes per forecast day.

As pointed out by Dexter (1974), the Barnett spectral wave model is one of the most complete now available for operational use. The primary difference between the Barnett model and the Pierson/NTU model used by FNWC lies in the method of energy propagation. While Barnett used sets of predetermined ray points along networks of fixed ray paths for propagation, the FNWC model calculates propagation by a finite difference approximation of the energy gradient between grid points. The Barnett model is well-suited to smaller bodies of water but would require several million ray sets to cover all ocean areas.

To overcome the computational storage requirements of the Barnett propagation technique, a Lagrangian interpolation scheme was programmed for FNWC by Ocean Data Systems, Inc. to determine the energy values at upstream points from a relatively small number of points on a uniformly spaced latitude/longitude grid. The Lagrangian interpolation modification, together with a grid system which has a latitude circle as the j coordinate, permits dividing the model

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into (a) a precompute program and (b) a wave prediction program. The precompute program accepts initial specifications of frequency bands, direction bands, time intervals, desired output and grid geometry. Once these are established, the precompute results are saved from one run to the next.

The wave prediction program is completely flexible in that the various parts are modular and switchable. All of the following sections are thus amenable to isolation and/or elimination. They are directed by input data control cards.

- ° Calculation of propagation
- ° Calculation of all growth terms
- ° Wind/wave interaction term
- ° Wave breaking term
- ° Wave/wave interaction term
- ° Low wind bypass
- ° High wind bypass
- ° Saturation limiting

In September of 1975, NDBO is scheduled to deploy a simplified spectral wave measurement system off Cape May, New Jersey. Buoy EB-41 will be equipped with a 12-channel Wave Spectrum Analyzer (WSA) and will transmit (synoptically) the average power passed by 12 active bandpass filters. Input to the filters is an analog voltage which is proportional to the vertical acceleration of the buoy. The Shore

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Communication Station in Miami, Florida will enter computed spectral densities into GTS circuits if the deployment is successful.

Systems for real-time measurement of ocean spectral waves are scheduled for deployment at an increasing pace. The models to make global forecasts of ocean spectral wave conditions now exist. FNWC will soon implement a global forecast capability; however, it is a military activity and is forbidden by law from providing services to commercial users. A strong requirement therefor exists for one or more national civil centers to develop a global spectral wave analysis/forecast service to meet the growing needs of an international user community. It is recommended that the IGOSs Committee take the lead in emphasizing this requirement.

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OCEAN DATA SYSTEMS, INC

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Submitted to:
ECON, INC.
Princeton, New Jersey

COMMENTS ON SPECIFICATIONS
FOR SHIPBOARD ENVIRONMENTAL
DATA ACQUISITION SYSTEM
ENGINEERING MODEL

Technical Note No. 4

Project No. 6613

June 1976

Prepared by
James M. Snodgrass
Roger L. Born
OCEAN DATA SYSTEMS, INC.
Monterey, California

15 August 1975

Mr. Roger Born
OCEAN DATA SYSTEMS, INC.
2400 Garden Road
Monterey, CA 93940

Dear Roger:

REF: National Weather Service Specifications for
Shipboard Environmental Data Acquisition System
(SEAS-1), Dated 5 May 1975.

Since we covered the bulk of our concerns over the telephone, I will simply first go through the document page by page, if you wish to refer to it, with general comments and then some kind of wrap up at the conclusion. I apologize that perhaps some of my remarks might turn out to be incorrect because of further qualifications later in the document. If so, I am sure you will spot the inconsistency, if I do not.

Page 1, Section 1.2 - As will be developed later, it would seem highly appropriate to make the initial installation on a "captive" ship that will not be going to foreign ports or be generally difficult to reach for any repairs or adjustments.

Page 2, Section 1.3 - In reading this, as well as later specifications, I do not believe that the line is sufficiently clearly drawn as to what is to be "initially a flexible experimental model" and the "next phase for development of more sophisticated sensor systems". I think this is a grey area. I have no difficulty with the specific example given, such as the XBTs, but I feel this would also relate to the particular types of sensors employed and, therefore, this becomes a very grey area.

The bottom paragraph on page 2 points out a vulnerable facet of the entire operation. Some of the sensors, such as water temperature and conductivity will, almost certainly, be located---for instance, in the case of a tanker---below the water line in some compartment below the deck probably in the engine room spaces. In the case of tankers, it should be pointed out that they are considered to be rather special ships and to simply put a hole in a bulkhead (perhaps even any bulkhead), requires very special permission from the proper branch of the U.S. Coast Guard. This, at the very minimum, will be involved and time consuming. The previous note, of

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course, assumes a hard-wired connection between the data processing unit and the sensor. There are, of course, alternatives to hard-wiring, one of the most easily adapted, though by no means without its problems, is to install a small, local FM converter to convert the signal output of the sensor to an FM carrier which is then coupled properly to the ship's internal electric lighting circuits. Since it is the practice in the marine field not to ground either conductor, this makes a particularly easy task of getting useful brute force transfer of the FM radio carrier to other points on the ship. Due again to considerations of ship safety, unquestionably the power would probably not be permitted to exceed 5 Watts which I think is quite adequate. In fact, 1 Watt might serve. However, some ships, I am certain, would require that the package that would be utilized to accomplish this purpose as well as the sensor package itself, if it is electrically powered from the ship's system, be qualified as an accepted piece of hardware, again by the appropriate Coast Guard group. To continue, a suitable FM receiver would then be required to be coupled to the power circuit at the location of the data processing unit. This basic system is by no means new, it has been used for at least 40 years by electric power companies for communications over power transmission circuits and for even turning on and off load systems in the domestic and industrial markets such as activating electric water heaters to absorb system power rather than accept a loss of generating efficiency under light load conditions. However, there are obvious flaws to this system, meaning that the FM conversion and demodulation all add to the potential system drifts and to maintain a specified accuracy requires careful engineering, even though one uses automatic calibration references. Though tankers are perhaps the worst ships, most government vessels will, nevertheless, require consideration of this type.

Page 3, Section 1.3 - (Top paragraph) - Since Figure 1-1 is a "preliminary block diagram", one should perhaps be prepared for changes being introduced that may or may not be easy to accommodate.

(Second paragraph) - The display of the environmental parameters may well be questioned as to what useful function this really performs; for example, as far as conductivity is concerned, in routine use what ship's officer or person who is likely to be on the ship will be in a position to do anything about this parameter. I think the whole business of displaying the measured parameters needs to be examined as to what benefits, if any, may be expected to accrue in an essentially automatic system. Some parameters I certainly can see, such as wind velocity, direction, etc. may well be of use, but in any case these do need to be examined.

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(Third paragraph) - Reference is made here to the installation of the engineering system on a NOAA ship. This is both good and bad. In the first place, it will have a highly critical group observing and troubles may well be reported which are very minor as far as the overall function is concerned, but can result in request to the manufacturer for immediate repair. Then, too, all NOAA ships are not necessarily easily accessible because they do range far and wide.

Also in this same paragraph it says that its performance will be evaluated which means there should be available for the manufacturer some idea of how the evaluation or rating, etc. is to be carried out. Certainly, there will be some ranking attached to various facets of the system and certainly the manufacturer should know what this will be.

It also refers to the fact that SEAS-I will serve to experiment with various sensor locations. I can see that this will have considerable problems because the question will come up as to who moves the sensors about. They may be damaged by personnel not responsible to the manufacturer and the question then is, who pays for the repair.

Page 4, Section 2, D. - The reference to the timer requires considerable engineering and development, as far as I can see, because of the necessity to perform decoding data from the GOES transmission. Certainly a significant number of man hours, engineering and fabrication would go into this item alone.

Page 5, Section 2, E. - the requirement of display on the bridge, regardless of location of the CTU, could be complicated. A small political question perhaps comes up as to whether the people having the approval of the location would accept the CTU on the bridge, which is usually a somewhat congested place. One might find it necessary to provide two display units.

Page 5, Section 2, F. - This section has somewhat of a booby trap in it, unless one provides for an automatic override of the alerting signal if it is turned off and not reset. This could cause many missed transmissions of essential data.

Page 5, Section 2.1, A. - This seems to be a rather unfortunately worded section in that it says, "These sensors shall be designed for mounting on the super-structure of the ship". Certainly, I do not believe that one would want to mount the wind speed or direction equipment at such a level and even air temperature may present some problems.

Page 5, Section 2.1, B. - The options here are particularly sticky since almost certainly, as we discussed, the output of the government furnished units will have to be

modified to minimize electromagnetic interference problems. This whole paragraph seems to me that the supplier or offeror is going to have to do a great deal of engineering on a whole variety of things that may not be elected.

Page 7, Section 2.1, D.5. - The provision here for call-up of display by switches as mentioned, seems to me potentially troublesome because the engineering will have to take into consideration that the operator will have to remember or re-set all switches when performing data entries or other operations so the amount of override and what happens when switches are turned needs to be specially considered. Also I believe there is nothing clear, at least as I have seen it, that says how much data must be displayed simultaneously rather than, perhaps, sequentially. This would seem to have a very large bearing on both the cost and design of the display system.

Page 7, Section 2.2 - I agree with you very much that the constraints specified by the standard 19" floor standing rack, etc. are rather crude and would, on the face of it, preclude a small box, desk top mounting, or bulkhead mounting. This seems to dictate that it must be a floor standing rack.

Page 8, Section 2.2, C. - One certainly needs some input data here that can be considered reasonably related to the parameters in terms of magnitude, time, or frequency, etc.

Page 8, Section 2.2, D. - This is a very real hazard which we have encountered because hinged access doors full length on a 60" rack and a heavy seaway can be very dangerous and, should they be used, adequate firm latching arrangements must be provided.

Page 8, Section 2.2, E. - This smacks very much to me of heavy duty military type equipment and I don't believe is the kind of thing either of us were considering.

Page 8, Section 2.2, G. - This is particularly troublesome because no number or specification is attached to what is considered "quiet". There are no acoustic specs and this certainly needs to have real numbers. Personally I trust that a blower would not be necessary.

Page 8, Section 2.2, H. - Both G. and H., I feel are particularly unsatisfactory because the basic design assumes that air is going to be blown through all of the electronic equipment. Since 99% relative humidity is envisioned with relatively high temperatures and, though they do not say so, salt air is going to be blown through the equipment, I feel this is archaic in terms of design and certainly requires very expensive encapsulation, etc. and special treatment, of course, of plugs, terminals, etc. to avoid corrosion.

Page 8, Section 2.2, I. - Connectors for external use or for interconnecting units on cables are simply invitations

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for trouble. This again reflects rather primitive design ideas.

Page 8, Section 2.3 - I think this is essentially a kind of boiler plate that can be made rather constraining or not, depending upon the whim, perhaps, of the government.

Page 8, Section 2.3.1 - This sections appears to me to be most indicative of the failure of the RFP writer to really understand what is going on. I understand that they wish to protect themselves against poor workmanship, etc. but I think the guarantee against failure essentially for a period of one year after acceptance is simply unrealistic and reflects substantial unfamiliarity with the general problems involved. (See Attached reference). This is essentially saying that there shall be a zero failure rate for one year. With an engineering model that must be built within a 6-month period from components or subassemblies for which even the manufacturer probably has only the vaguest idea of their reliability in terms of failure rate as a function of time, this poses an almost impossible task. This is doubly true because many of the subassemblies or components which we discussed are too new to possibly acquire suitable failure rate or MTBF (Mean Time Between Failure) within the allotted time period. Certainly all of this takes great liberty with the laws of probability. I would feel that one could not honestly or conscientiously deliver a piece of equipment guaranteed for a zero failure rate for a year under the short time frame or, for that matter, dollars available. Here again, a significant redoing of the guarantee should be done and perhaps, if they wish to enforce the 6-month period, it would be well to simply accept failure if it occurs, but then an independent analysis of the failure by the proper engineer should not conclude that the failure was caused by faulty engineering on the part of the supplier. This, of course, is a difficult area for specifics, but I think it needs to be developed. As I mentioned earlier, if this kind of equipment is installed on a NOAA ship, there will be all kinds of demands that something is not functioning properly and, having been through this, often these are under the category of "cockpit problems" and the manufacturer will find that a great deal of engineer's travel time is involved simply pointing out to people that they were, themselves, making the mistakes. The relationship on Page 9 of this same section in which it is stated that the repair must be completed within 30 days after notification by the government of the defect could be a real hassle. Perhaps the ship is not in port or, if it does get into port shortly thereafter, and should it be necessary to return the failed part or parts to the manufacturing plant, this can eat up a great deal of time. This 30-day business, I think, needs to be straightened out.

Page 10, Section 2.5 - We covered some of this over the telephone, but some of it we can go over again. Perhaps the sea water temperature accuracy (RMSE) of 0.1°C causes considerable question. If I remember correctly, several years

ago I found out (perhaps with Paul Wolff's assistance) that the atmospheric models which were utilizing the sea surface temperature simply were not sensitive to the 0.1°C and would be perfectly happy with even an accuracy as large as 1°C . I think it was none other than Dr. J. P. Tulley of Vancouver who said quite a long while ago when this problem was being discussed that, "The sea doesn't know its own temperature this accurately". What he was referring to, of course, is that there are large gradients on the surface and that any realistic values represent in general an area integration or average and certainly, as far as the projected satellite "footprints", these will amount to diameters of several nautical miles. Certainly, to ask for one tenth of a degree accuracy when one degree will actually suffice, certainly in an engineering test unit of this type, is unreasonable. It drives up the cost very significantly. This, of course, becomes quite obvious when one considers that this spec, over the operating range, means the resolution and accuracy must be one part in 450. Then, too, this neglects the philosophical question of how one can have a system of this type with an RMSE accuracy the same as the sensitivity.

As far as wind speed is concerned, this again poses an interesting problem because both the accuracy and the sensitivity are identical and twice the magnitude of the reporting resolution. The 120 knot magnitude tends to pretty well eliminate some sensors and one of the best sensors which I am aware of is the J-Tech vortex shedding unit which, as we discussed, if mounted on a mast or a base that is subject to much vibration may generate rather peculiar outputs. Since no specification is given in all of this for the amplitude and frequencies of anticipated vibrations, such as the top of a ship's mast, for sensors that might be mounted there, I think there are some real questions at this point. Certainly the specifications are inconsistent as far as wind speed is concerned with the definitions contained on the page. I must confess that at the moment I do not know if the JTech Vortex Shedding Unit undergoes significant degradation in a rain storm.

Page 13, Section 2.7 - Certainly this paragraph implies that all of the sensors will be connected with a hard wire system and this may or may not be practical as developed in earlier paragraphs.

Page 14, Section 2.8 - A point occurs to me here with respect to potential outages as long as 30 seconds. Since the clock is controlled basically by the signal from the GOMS satellite, what are the relationships here to getting the system up and running again.

Page 14, Section 2.9 - Certainly it seems the documentation is very extensive and a considerable number of man hours would be required to prepare the non-software portion of the manuals and I would certainly think that your department in the software area is also very demanding.

Page 15, Section 2.11 - The spare parts request here I think must be looked at also in light of Section of 2.3.1 relating to the guarantee because, if the whole thing is presumed to be on the basis of a zero failure rate for a year period, why any spare parts? Furthermore, it implies here that the government will pay for the spare parts. This is in contradiction to the contractor having to pay for repairs of a failed part.

Page 15, Section 2.12 - A question here, of course, is: if this training period to begin after the 6-month period when the equipment is delivered or must this be absorbed within the 6-month period? If it is within the 6-month period the contractor certainly could not count on having access freely to the equipment.

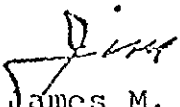
Page 17, Section 4. - In the top paragraph, next to the last line is "support of the SEAS-1 installation". Though it implies that the government employees will carry out the actual installation, I think the word "support" is capable of rather broad interpretation and this could imply a very significant amount of man power and effort on the part of the contractor under some conditions. Therefore, I think this needs to be clarified.

The next paragraph on this page, by the way, is an addition to your total dollars to play with because here it is asking that the man hours and the engineering for the installation come within the basic contract! This whole area of installation and field support is a delicate one because I am certainly familiar, and I am sure you are, with equipment that has been damaged or rendered inoperable because of action on the part of the installing personnel. Some kind of insurance here somehow needs to be worked into this.

Pages 17 and 18 - I don't detect quickly any specification that dictates how the equipment is to be shipped. I am partial to air freight in things of this sort, or at least an air shipment, but I am not sure that this is acceptable to the government.

So much for the comments, let me know if I can assist further.

With best regards,


James M. Snodgrass
Senior Technical Director

JMS:c

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Attachment

SYSTEM ENGINEERING HANDBOOK

EDITED BY

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IN COLLABORATION WITH

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example, a satellite might be required to have a 90 per cent probability of successful operation for a period of 1 year, in orbit.

Several classes of operation may be considered:

1. Continuous operation for long periods. Example here would be an air-traffic-control system, a satellite, or communication equipment.
2. Operation for short period, when operation is preceded by a test for correct functioning. An example would be a missile guidance system.
3. One-time-use operation where testing is not practical (such as solid propellant rocket).

Exponential Failure Law, Mean Time to Failure. While complex systems or equipments may fail, as a function of time, in a variety of ways, it has been found that electronic equipment tends to have a characteristic failure behavior. This behavior is illustrated in Fig. 33-2 and is characterized by three principal stages.

Stage 1 is the early life of the equipment and exhibits a high but rapidly declining failure rate as the best-fixed and potential components are discovered and eliminated by a "debugging" process. Stage 2 is a period of increasing numbers of failures due to wear-out process after extended use. Stage 3 is a period of relatively constant rate of failure characteristic of the mean operating life of the equipment, in which failures occur randomly and infrequently.

The curve is obtained by plotting smoothed data from equipment life tests in which failures are quickly repaired so as to keep the population constant. The infrequent random failures will smooth to a flat failure rate curve, hardly increasing rapidly in the

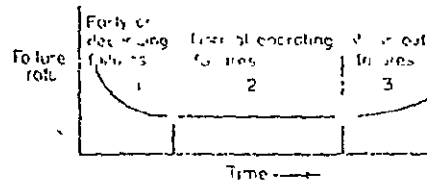


Fig. 33-2 Failure-behavior curve.

wear-out region. The flat portion establishes the normal operating region, and here failures can be considered random and independent, corresponding to a Poisson process. Such a failure behavior is also used as a point of reference in reliability engineering as it permits reasonable predictions of reliability from short-time test data.

In examining the data from life tests, it can be found that for a Poisson process the intervals between failures follow a characteristic pattern: many short intervals, few longer ones, and very few extremely long intervals. When the numbers of occurrences of different time intervals are plotted, an exponential curve is formed. This exponential curve should not be confused with the shape of the curve of Fig. 33-2—we are speaking only of the law of stage 2 portion. This leads to the exponential failure law

$$R = e^{-\lambda t} = e^{-t/\theta}$$

where R = reliability or probability of successful operation for the time t

λ = failure rate

m = inverse of the failure rate or mean time between failures (MTBF)

The system designer is concerned with the reliability of an equipment operating without failure for a given length of time. When the length of this period is equal to the MTBF, the reliability (or probability, R) is 0.368. Notice that, to obtain a higher value for R , the value of t must be less than the mean length. For example, for $R = 0.9$, $m \approx 10t$; for $R = 0.99$, $m \approx 100t$.

Reliability engineering is concerned with the distribution of failure in the time domain, not with the distribution of defects in a population as in quality control. It is important to recognize that a major problem is that of determining the actual distribution of failures in the time domain. This usually requires a testing program.

With respect mean 100% Reliability would require after 1 year.

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The test should be carried on long enough to determine the duration of the flat portion of the failure curve; however, there is no need to determine the exact nature of the distribution in stage 3, as prediction is not possible in this region. Many different distributions, calling for different mathematical models, are found in testing electronic parts. Among the models found useful are Gaussian, Poisson, and Weibull (see Table 33-3) are of particular interest.

Reliability Prediction. As was pointed out in Fig. 33-1, one of the key steps in the attainment of a reliable system is the prediction of its reliability. Such predictions are required for a variety of purposes, e.g., evaluation of alternative designs, to determine whether a proposed design meets the stated requirements of the system, or to determine which portions of a system design are the "weak link" from the standpoint of reliability. Where the objective is a comparison, good results are readily obtainable as long as the analysis is done in the same way in each case and the base data are comparable. Where the objective is a prediction of the absolute value of the reliability, the problem is more difficult and the technique is called for in the preparation of the mathematical model and in the choice of reliability data.

The most generally used prediction technique for predicting the reliability of electronic equipment calls for the following:

1. List the quantities of each different part used.
2. Multiply each quantity by its failure rate and sum the total, to obtain the overall failure rate.
3. Calculate the resulting reliability of the equipment from the exponential law, using the overall failure rate.

The particular expressions used are

$$\begin{aligned} R_{\text{system}} &= R_1 \times R_2 \times R_3 \times \cdots \times R_n \\ \text{or} \quad R_{\text{system}} &= e^{-\lambda_1 t} \times e^{-\lambda_2 t} \times e^{-\lambda_3 t} \times \cdots \times e^{-\lambda_n t} \\ \lambda_{\text{system}} &= \lambda_1 + \lambda_2 + \lambda_3 + \cdots + \lambda_n \end{aligned}$$

The technique depends on the following assumptions:

1. All parts have constant failure rates, i.e., they are in the stage-2 period and consequently the exponential law applies.
2. The failure-rate data are available and agree with the environment found in this equipment.
3. For successful operation of the equipment, every part must operate.
4. Failure of one part is independent of failure of the others.

The validity of these assumptions must be carefully considered when this technique is used in order to avoid substantial errors. For example, many types of complex equipment, such as electronic computers, do not at all times use every element of the system. This must be taken into account in calculating the system reliability lest the calculated result be unduly pessimistic. A large number of operating, standby equipment, and other redundant elements further complicate the problem. In connection with point 4, many or most component parts of a system will commonly share the same physical environment (e.g., the same power and air-conditioning source) and in various ways have failure characteristics which are not completely independent. The matter of obtaining reliable and pertinent data on component part and failure rates is one of the chief problems in reliability prediction. Despite these hazards, reliability predictions have been developed to the point of quite good accuracy.

33-3. The Constituents of Reliability

This section is concerned with the "materials" or ingredients with which the system designer has to work in attaining his reliability objectives. It has to do with the nature of the physical parts which are available as well as with the factors which constitute the environment (taken in the broadest sense) in which the physical component will be produced and used. To some degree, these elements are under the system designer's control, at least insofar as he can protect from or emphasize certain ones, but



OCEAN DATA SYSTEMS, INC.

Memorandum

To: Paul M. Wolff
From: Roger Born
Date: August 15, 1975
Subject: SEAS-1 RFP

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When I first saw the RFP for the Shipboard Environmental Data Acquisition System Engineering Model (SEAS-1), I was quite thrilled. An acquisition system for ships-of-opportunity is certainly a long-needed product. Reliable and regular weather data from the ocean has long been a major hole in WMO data collection. With the First GARP Global Experiment (FGGE) coming up, the need is further underscored.

With the current state-of-the-art in integrated circuit technology, particularly large-scale integration (LSI), an automated shipboard ship-of-opportunity weather station of reasonable size, high reliability, low power consumption and minimum operator attention is now feasible. Problems which have plagued shipboard installations for years are now solvable, as is clearly demonstrated by the special acquisition systems developed for the GARP Atlantic Tropical Experiments (GATE). Automatic reporting has been demonstrated by the NOAA Data Buoy Office. This experience, combined with LSI technology -- especially the new micro-processor technology, opens the door to a viable and relatively inexpensive ship-of-opportunity environmental data acquisition system.

My enthusiasm died rather rapidly, however, as I got into the Statement of Work and discovered that delivery was expected within six months. This implies an off-the-shelf product. Even then it's tight, allowing very little lead time for component or subsystem procurement. The dismay comes not from the implication to procure an off-the-shelf SEAS-1 system; rather, in my conviction that there isn't any off-the-shelf product that will meet the requirements. The data acquisition systems built for the NOAA Data Buoy Office Limited Capability Buoys are the closest I know to satisfying the requirements.

They are designed, however, to operate in an electrical environment that is relatively quiet. When sensors are remoted in a ship-of-opportunity environment which has a high level of electrical and radio frequency interference (RFI) they will not work.

Time can be roughly related to dollars. Based on my experience, six months would roughly translate to \$50,000 or \$75,000. This amount would be adequate to buy an off-the-shelf system and some support services.

It would not be adequate to buy the programming necessary to implement automatic transmission of calibrated and error-free data. It certainly would not be adequate to develop a system using state-of-the-art technology. Considering the number of units that will be eventually deployed, a development using latest technology is the proper way to go.

Further reading of the Statement of Work makes one question whether or not adequate attention has been given to unique shipboard problems. No mention has been made of the extremely high RFI existent on ships. This problem is particularly troublesome with remotely-located sensors producing low-level signals which must be transmitted significant distances to the collecting equipment. In manual systems, this problem was adequately attacked with cable shielding, since the analog readout instrument generally had a long time constant. Noise transients which came through would be detected by the trained human reading the instrument and either mentally discarded or visually integrated. Past techniques of instrument shielding are not adequate in automatic digital systems. It takes very sophisticated programming to do what the human does in an analog system. This problem was solved in GATE by placing analog-to-digital conversion equipment within a few feet of the sensor, returning a pulse coded and frequency modulated signal to the collecting equipment. RFI was completely eliminated except from the sea-surface temperature sensor, which had 30 feet of wire between the sensor and the A/D converter.

A second technical area disturbing to me is that related to the sea-surface temperature and conductivity measurements. Specially designed research ships obtain these measurements by bringing water in through a special bow opening to a sea chest where the sensors are

placed. During GATE an attempt was made to measure sea-surface temperature from an overboard sensor away from the influence of the ship. Even in a stationary on-station ship this became a very difficult problem to solve. In truth, it was never satisfactorily solved. Obtaining sea-surface temperature and conductivity measurements from a moving ship-of-opportunity is neither straightforward nor a simple problem to solve. Delivery of hardware embodying a satisfactory solution in six months seems somewhat ludicrous.

Lastly, I am not sure the Statement of Work adequately anticipates the computer programming required. Before true winds can be calculated, individual samples must be averaged which implies a conversion from wind speed direction to wind vectors. Prior to this conversion, the raw digital data must be converted to scientific units and scaled. Editing should be performed on data elements to remove bad data prior to averaging. A continuous check on instrument calibration should be made, requiring additional calculation. This kind of processing must be done for each instrument. In addition, the re-conversion of parameters from a form convenient for computation into a format for transmission must be made. Transmission control, display and manual input programs are required as is the development of a real-time executive program. Programming, debugging and program checkout is much more than a six-month job. To do the same job for the GATE systems, albeit for a larger suite of instruments, required four times that amount of time and approximately \$200K.

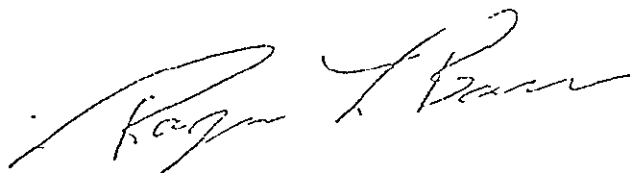
I believe an ideal solution for SEAS-1 would be a distributed processing approach using small four-bit micro-computers at the sensor interfaces, in the manual keyboard input and display, and at the Data Collection Platform Radio Set (DCPRS). Portions of the processing would be done at each of these points. Interconnect cabling would reduce to twisted pairs for signal transmission. The noise problem would be solved; packaging could be small, convenient and amenable to conductive cooling.

A design study addressing the application of state-of-the-art technology would seem to be a more appropriate allocation of limited funds at this time. One can learn from GATE instrumentation experience (which learned from BOMEX) as well as data buoy experience. New technology can be incorporated prior to equipment procurement. This would

certainly be a less costly approach in the long run.

If a test bed for sensor development is desired, NOAA could use one of the GATE systems. It is much better suited to this purpose as it has recording capabilities in addition to a wealth of test instrumentation. By interfacing the DCPRS to the system, real-time collection of data and transmission to the satellite on a three-hourly basis can be tested. A hardware interface and a small amount of programming would be required. The basic software can run in real-time, though this mode saw only limited use in GATE.

In light of the above considerations, I recommend ODSJ no-bid the RFP for SEAS-1.



Roger L. Born

RLB:mvj

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